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Human Acclimation and Acclimatization to Heat: A Compendium of Research— 1968-1978

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(NASA-TM-81181) HUMAN ACCLIMATION AND
ACCLIMATIZATION TO HEAT: A COMPENDIUM OF
RESEARCH, 1968-1978 (NASA) 104 p
HC A06/MF A01

N80-34056

CSCL 06P

Uncclas

G3/51

28835

August 1980



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INTRODUCTION

The purpose of this compendium is to gather together under one cover the majority of works that elucidate the mechanisms of short-term acclimatization and acclimation to heat. Additional studies are included that provide background information in the form of reviews or classic descriptions of the process. These abstracts are a continuation of a previous volume entitled "Human Acclimation and Acclimatization to Heat: A Compendium of Research," by John E. Greenleaf and Carol J. Greenleaf, which was published as NASA Technical Memorandum X-62,008, in December 1970. That volume presented abstracts of material from early works through December 1967. This compendium includes material published from 1968 through December 1978. The abstracts are listed in alphabetical order by first author and are numbered serially. A subject index is provided. Note that numbers shown with the index entries are abstract numbers, not page numbers.

As in the previous volume, a particular study was selected for this bibliography because of its relevance to the elucidation of short-term acclimation and acclimatization to heat. Where necessary, a detailed annotation is provided under the subheadings: (a) purpose of study, (b) subjects, (c) conditions, and (d) results and conclusions.

The following definitions are used:

1. *Adaptation*: changes on the phylogenetic level that have been fixed in the heritage of any particular species.
2. *Acclimatization* (natural): long-term responses throughout the life of an individual to complex of environmental variables. The term *heat* acclimatization could not be used if reference was only to the effects of heat on the organism.
3. *Acclimation* (artificial acclimatization): the day-to-day organismic changes due to the effect of a single environmental variable as would be used in controlled laboratory conditions.
4. *Habituation*: a change in physiological response resulting from a decreased response of the central nervous system to constant stimuli.

We thank our many colleagues who provided reprints of their work, and apologize to those whose studies we have inadvertently overlooked.

1. Adams, W. C.; Fox, R. H.; Fry, A. J.; and MacDonald, I. C.: Thermoregulation During Marathon Running in Cool, Moderate, and Hot Environments. *J. Appl. Physiol.*, vol. 38, 1975, pp. 1030-1037.

Authors' Abstract

A well-trained subject, age 38, ran continuously for periods ranging from 60 to 165 min on a motor-driven treadmill at 255.7 m/min while confronted with an airflow equivalent to running speed in cool, moderate, and hot environments. After a period of intensive heat acclimatization, treadmill runs were repeated in the moderate and hot conditions. Measurements were also obtained outdoors in a competitive marathon race. Sweat rate (SR) and mean skin temperature (\bar{T}_s) were linearly related to T_{ab} . Acclimatization did not alter $\dot{V}O_2$ max or metabolic rate during the treadmill runs, but heart rate (HR), rectal temperature (T_r), and \bar{T}_s were lower, SR was higher, and maximal run duration longer in the hot environment, postacclimatization. Maximum runs in the hot environment were terminated by a spiralling increase in T_r to hyperthermic levels, due largely to a marked reduction in cutaneous blood flow, probably reflecting cardiovascular overload from the combined muscular and thermoregulatory blood flow demands, coupled with the effects of progressive dehydration. Utilizing partitional calorimetry and the subject's metabolic heat production, two examples of limiting environmental conditions for his marathon running speed were given.

2. Allan, J. R.; and Wilson, C. G.: Influence of Acclimatization on Sweat Sodium Concentration. *J. Appl. Physiol.*, vol. 30, 1971, pp. 708-712.

Authors' Abstract

Experiments were undertaken to clarify the effects of heat acclimatization on the sodium concentration of sweat and to distinguish these from the effects of concomitant changes in sweat rate. Sweat samples were collected at different rates of sweating from three unacclimatized subjects, using a Perspex capsule containing filter papers. The subjects were then acclimatized to heat, using a passive hyperthermia technique, and a further series of sweat samples obtained at different rates of sweating. The weighed samples were analyzed for sodium concentration and the results used to plot sodium concentration against sweat rate before and after acclimatization. The results show significant reduction in sweat sodium concentration with acclimatization over a wide range of sweat rates. Possible mechanisms are discussed.

3. Ansari, A.; and Burch, G. E.: Influence of Hot Environments on the Cardiovascular System. *Arch. Intern. Med.*, vol. 123, 1969, pp. 371-378.

Authors' Abstract

Twenty-three patients with cardiac failure were observed clinically at rest in neutral (75°F, 41% relative humidity [RH]), hot, dry (90°F, 41% RH), and hot, humid (90°F, 75% RH) environments. Fifteen patients developed clinical evidence of overt congestive heart failure in the hot, dry climate; 18 developed symptoms in the hot, humid environment, two having episodes of angina. Seventeen patients displayed T-wave changes in their electrocardiograms in both hot environments, and 9 showed significant changes in their vectorcardiograms. Venous pressure increased in both hot environments in 12 patients, decreased in 6 in the hot, dry environment, and decreased in 5 in the hot, humid atmosphere. Body temperature, pulse, respiratory rate, and blood pressure increased in the heat in most patients. The hot, humid environment was less tolerable than the hot, dry one and imposed a greater burden on the cardiovascular system, especially in patients with the most advanced heart disease.

4. Araki, T.:
 The Effect of Physical Training on Sweating Responses Measured During Muscular Exercises and Resting Postures in Hot Environments.
Kobe J. Med. Sci., vol. 22, 1976, pp. 17-33.

Annotation

Purpose. To examine the effects of physical training on the sweating responses of individuals at rest or engaged in an exercise in a hot environment to show their adaptive abilities to the heat.

Subjects. Twenty-two males, mean age 20, mean height 169 cm, mean weight 58.45 kg; 11 subjects trained, 11 subjects untrained.

Conditions.

DBT/WBT/RH	Air	kcal/(m ² ·hr)	Regimen
1. 28.5/-/- 35.0/-/- 40.0 45.0/-/-	---	---	1. 6 trained, 6 untrained subjects: 0.5 hr ambient rest, followed by 2 kg bicycle ergometer exercise for 1 hr
2. Day 1: 45/35.5/50 Day 2: 48/38/53	---	---	2. Day 1: 3 hr sitting rest Day 2: 2 hr sitting rest 5 trained, 5 untrained subjects
3. 43/35.4/60%	---	---	3. 60 consecutive days of 7-km running, with pre/post heat exposure while sitting at rest for 1 hr 1 subject
4. 45/38/60%			4. Same as No. 3 above

Author's results and conclusions.

The sweat rate was well maintained in the trained group at individual steady levels just after the rapid initial increase due to the exercise and at rest with each individual maintaining particular ambient thermal loads. Furthermore, the trained group was characterized by lower sweat Cl concentration and a smaller increasing degree of rectal temperature than the untrained group throughout the exercise and rest periods conducted in hot environments. Continuous physical training for untrained men provided one who was resting in a hot environment with the characteristic sweating responses of the trained group. The results indicate that physical training provides reasonable sweating responses to both muscular exercise with external heat stress and heat stress alone. They also strongly suggest that physical training has an effect on thermal adaptability. However, the effects of training may be virtually negligible depending on the intensity of a given stimulation.

5. **Baron, R. A.; and Bell, P. A.:**
Aggression and Heat: The Influence of Ambient Temperature, Negative Affect, and a Cooling Drink on Physical Aggression.
J. Personality Social Psych., vol. 33, 1976, pp. 245-255.

Authors' Abstract

Two experiments were conducted to examine the influence of ambient temperature upon physical aggression. In the first, male subjects received either a positive or negative evaluation from a confederate and were then provided with an opportunity to aggress against this person by means of electric shock. On the basis of previous research, it was predicted that high ambient temperatures (92°-95°F) would facilitate aggression by those receiving positive evaluations but actually inhibit such behavior by those receiving negative assessments. Results confirmed both of these predictions and also indicated that more moderate but still uncomfortably warm temperatures (82°-85°F) produced similar effects. The second experiment employed procedures similar to the first and examined the suggestion that administration of a cooling drink would reduce the impact of high ambient temperatures upon overt aggression. This prediction, too, was confirmed. The possible mediating role of negative affect with respect to the influence of ambient temperature and other environmental factors on aggression was discussed.

6. **Bar-Or, O.; Harris, D.; Bergstein, V.; and Buskirk, E. R.:**
Progressive Water Loss During Heat and Work Stress in Men and Women.
Int. J. Biometeor., vol. 13, 1971, pp. 81-99.

Authors' Abstract

Subjects underwent two walking sessions at 38.6°C dry bulb and 21.9°C wet bulb lasting 6 hr each, at the end of which they reached weight losses of 2.4% ("low loss") and 4.2% ("high loss") of their initial weight. Walking conditions were 5.6 km/hr at 5% grade for the "high loss" session and 5.6 km/hr at 0% grade for the "low loss" session. Drinking was not allowed. Two control sessions were held under comparable exercise and climatic conditions, but periodic drinking kept weight loss negligible. Plotted against percent weight loss, rectal and skin temperatures, exercise heart rate (HR), and orthostatic HR response showed continuous increase. Sweat rate and distribution of heat-activated sweat glands did not change. HR was the only parameter that was markedly higher in the "high loss" session compared with the "low loss" one, at all percent weight loss levels. The HR of women, unlike other measurements, was distinctly higher than that of men at a given percent weight loss. This study indicates that the percentage of water loss may determine the level of physiological heat strain even at mild degrees of hypohydration, in men and women alike.

7. **Bar-Or, O.; Harris, D.; Bergstein, V.; and Buskirk, E. R.:**
Progressive Hypohydration in Subjects Who Vary in Adiposity.
Israel J. Med. Sci., vol. 12, 1976, pp. 800-803.

Annotation

Purpose: To study the effects of hypohydration caused by exercise in the heat in obese and lean subjects.

Subjects: (\bar{x})	Age	Ht., cm	Wt., kg	Surface Area, m^2	% Fat	Number
Obese	22.3	174.4	92.3	2.07	24.9	2 males, 2 females
Lean	21.8	170.6	57.2	1.66	13.2	2 males, 2 females

Conditions.

<i>DBT/WBT/RH</i>	<i>Air</i>	<i>kcal/(m² · hr)</i>	<i>Regimen</i>
38.5/22.0/23.5			7 total exposures in the same order for all subjects. A. 3 days orientation. B. Week 1: Two 6-hr test sessions with intermittent treadmill exercise (20 min., 4.8 km/hr, 0% grade) and supine rest (30/40 min), to -2.5% body wt. One test session with ad-libitum water intake and the other no fluid allowances. C. Week 2: Same as Week 1 except exercise at 4.8 km/hr and 5% grade to achieve 5% reduction in body weight.

Results.

1. Rate of fluid loss for all subjects was the same throughout a given session, irrespective of the level of hypohydration.
2. A higher rise in final rectal temperature was seen for the obese hypohydration, especially during the 5% weight reduction exercise, when it was 38.1 for the lean and 38.7 for the obese.
3. Final skin temperatures at the 5% weight reduction stage were 36.2°C for the lean and 35.6°C for the obese.
4. HR rose linearly with weight loss, and was consistently higher in the 5% weight reduction test for the obese subjects by 5 to 10 BPM at all levels of hypohydration. Peak mean values were 162 (obese) and 153 (lean) BPM.
5. Heat activated sweat gland density remained constant for each individual throughout the various test stages, regardless of the hydration state.
6. In every session there was 20% to 25% lower heat activated sweat gland density in the obese subjects.
7. The mean sweat production per sweat gland was about 40% higher in the obese subjects, indicating a heat strain.
8. Urine volumes of the lean subjects (per kilogram body weight) were almost twice as high as those in the obese subjects.

Conclusion.

The increments in body temperature, as well as the sweating responses, indicate that for a combined stress of heat, exercise, and moderate hypohydration, the relatively obese subjects suffered a higher strain than the lean subjects.

8. Bar-Or, O.; Lundgren, H. M.; and Buskirk, E. R.:
Heat Tolerance of Exercising Obese and Lean Women.
J. App. Physiol., vol. 26, 1969, pp. 403-409.

Authors' Abstract

Five obese and four lean women were each exposed to six different walks in controlled environments ranging from warm to hot. Walking conditions were 4.8 km/hr and the environmental range was 21.1°-35.0°C effective temperature with a relative humidity of 13-20%. Environmental conditions were kept constant during a given session. With either the "critical effective temperature," in which rectal temperature becomes dependent on the heat-stress level, or the heat stress at which rectal temperature reaches 39.2°C as criteria for heat tolerance, the women showed tolerance similar to that reported for comparably acclimatized men who performed similar work loads. The obese women were under higher heat strain than were the lean, a difference which diminished with increasing heat stress. The latter finding may be explained by a larger surface area per kilogram in the lean which at high ambient temperatures results in the imposition of a greater relative heat load via radiation and convection in the lean as compared to the obese.

9. Bar-Or, O.; Lundgren, H. M.; Magnusson, L. I.; and Buskirk, E. R.:
Distribution of Heat Activated Sweat Glands in Obese and Lean Men and Women.
Hum. Biol., vol. 40, 1968, pp. 235-248.

Annotation

Purpose. To determine the total and regional differences in the counts of heat-activated sweat glands between obese and lean men and women.

Subjects. Four lean men, four lean women, four obese men, and four obese women. (Obese = 25% fat or more, as determined by skinfold measurements.) Mean age 19.6 yr.

Conditions:

DBT/WBT/RH	Air	kcal/(m ² ·hr)	Regimen
47/24/14	16 m/sec	---	After 45 min of heat exposure, heat activated sweat glands (HASG) were measured on 18 trunk sites and 28 limb sites.

Authors' Results.

1. Higher HASG densities were found in the lean than in the obese and in the women than in the men. The difference in HASG density between the lean and the obese was primarily in the trunk in both men and women, but also on the limbs in women. The higher counts in the women may result from the moderate level of heat stress employed.

2. Skinfold thickness was measured in the women from sites identical to those used for HASG counts. An inverse relationship was found between HASG density and skinfold thickness both on an interindividual and intraindividual basis. The latter was demonstrated in the limbs only and may not imply a physiological cause and effect relationship between subcutaneous fat deposits and HASG density.

3. An inverse relationship was found between average HASG density and percent body fat, in the women. The women with large body surface area had, generally, lower HASG densities than had those with smaller surface area.

10. Beals, K. L.:

Head Form and Climatic Stress.

Am. J. Phys. Anthropol., vol. 37, 1972, pp. 85-92.

Annotation

Purpose. To determine the relationship between climatic stress and head form.

Subjects. Compiled mean cephalic indices from 339 living populations taken over a span of 70 yr (1894, 1898, 1926, 1928, 1937, 1945, 1953-57, 1959, and 1964).

Conditions. Samples were arranged in delineated generalized zones of traditionally recognized classes of stress:

1. Dry heat — Hot desert areas with high maximum temperatures and generally cool nights (warmest month mean from 20° to 30°C).
2. Wet Heat — Tropical forest regions having lower maxima but more humidity (warmest month means from 20° to 30°C).
3. Dry cold — Continental areas (coldest month mean from less than -30° to 0°C).
4. Wet cold — Maritime climates with high humidity (coldest month means from -10° to 10°C).

Results.

The mean cephalic index in major climatic stress zones:

	\bar{x}	SE	Number of Means
Dry heat	75.98	0.29	124
Wet heat	78.68	0.31	121
Wet cold	80.54	0.46	34
Dry cold	82.25	0.45	60

Author's conclusion.

Populations living in cold climates are more likely to have rounder heads (brachycephalic) than those dwelling in hot climates.

11. Beisel, W. R.; Goldman, R. F.; and Joy, R. J. T.:

Metabolic Balance Studies During Induced Hyperthermia in Man.

J. Appl. Physiol., vol. 24, 1968, pp. 1-10.

Author's Abstract

Metabolic responses in men were studied during hyperthermia — induced by humid heat. Conditions in an environmental chamber were adjusted to increase rectal temperatures 0.1°-0.2°C/hr for 18 hr and to hold them at 39.4°C for 6 hr. After rising initially, skin temperature followed a similar pattern. Urinary 17-OHCS, 17-KS, and pregnanetriol increased during hyperthermia and afternoon plasma 17-OHCS concentrations failed to fall. Negative nitrogen, potassium, and magnesium balances were produced by diminished dietary intake, increased urinary excretion, and sweat losses. Urinary sodium and chloride fell abruptly; their renal retention persisted 3 days following heat exposure. Orally administered tap water during a continuing production of sweat caused dilutional decreases in concentration of serum inorganic elements. Hypophosphatemia was exaggerated, possibly because of respiratory alkalosis. Phosphate losses in urine and sweat were minimal, preventing appreciable loss of body phosphorus. Adrenal responses and alterations in nitrogen metabolism during artificial hyperthermia resembled changes seen in infectious fevers. In contrast, body salt and water metabolism was influenced by greater sweat losses during induced hyperthermia.

12. **Bell, C. R.; and Walters, J. D.:**
Reactions of Men Working in Hot and Humid Conditions.
J. Appl. Physiol., vol. 27, 1969, pp. 684-686.

Authors' Abstract

The physiological reactions of 31 unacclimatized young men exposed to hot and humid environments ranging from $37.5^{\circ}/33.9^{\circ}$ to $53.0^{\circ}/48.3^{\circ}\text{C}$ dry bulb/wet bulb temperature with an air speed of 102 cm/sec and approximately equal air and mean radiant temperatures, were studied. Subjects worked continuously during exposures at an estimated 280 kcal/hr until a state of imminent heat collapse was attained. From these data, together with data from a similar experiment on eight young men, it was possible to construct a curve relating safe exposure times to a description of climatic severity. Safe exposure was defined as that time within which only 5% of a population represented by the men studied, in conditions similar to those investigated, should reach a state of imminent heat collapse or within which each man would have only a 5% probability of reaching a state of imminent heat collapse. The suggested safe exposure times were from 52.9 min at the lowest temperatures to 5.9 min at the highest temperatures.

13. **Benor, D.; Shvartz, E.; and Sa'ar, E.:**
Natural Acclimation to Heat in Inhabitants of Semi-Desert Areas in Israel.
Israel J. Med. Sci., vol. 8, 1972, p. 1016.

Authors' Summary

Eleven young male residents of Beersheba were studied in order to compare the effect of natural acclimation in inhabitants of semi-desert areas with artificial acclimatization. The latter was recently investigated (1). Two identical work-heat tests were administered in winter (January) and in summer (August) of 1971. The tests consisted of walking on a treadmill at a speed of 5.6 km/hr up a 5% slope, with a room temperature of 50°C and 20% relative humidity. Some results of the summer, as compared with the winter, tests indicated a slight degree of acclimation, manifested by a significant increase in sweat rate of 0.088 liter/m² per hr, or 13% and a marked decrease in skin temperature of 1.1°C (weighted average). However, the other parameters measured did not indicate acclimation: the average rectal temperature exhibited a negligible decrease of 1.1°C ; the average heart rate decreased insignificantly by 8 beats/min; tolerance time increased in only four subjects, remained unchanged in four and decreased in three. Only two subjects showed an overall improvement in natural acclimation equal to known improvement with artificial acclimatization (E. Shvartz et al., submitted for publication). It may be concluded that natural acclimation among inhabitants of a semiarid zone is less efficient than artificial acclimatization, and does not suffice to overcome the stress of work in extreme heat.

14. **Berglund, L. G.; and Gonzalez, R. R.:**
Evaporation of Sweat From Sedentary Man in Humid Environments.
J. Appl. Physiol.: Respirat. Environ. Exercise Physiol., vol. 42, 1977, pp. 767-772.

Authors' Abstract

Physiological and sensory responses were observed in four male subjects while they were seated on a balance. The chamber temperature always equaled mean skin (\bar{T}_{sk}) ($34^{\circ}-36^{\circ}\text{C}$), thus eliminating all sensible heat transfer. Ambient water vapor pressure (P_a) was increased in steps from 10 to 40 Torr. Tests at air velocities from 0.1 to 2.4 m/sec were conducted with subjects nude and clothed. Esophageal temperature (T_{es}) and \bar{T}_{sk} , heart rate (HR), and weight loss (M) were measured throughout the 2.5-hr tests. After each 25-min humidity step subjects recorded their warm discomfort, sensation of sweating, and thermal sensation. Results: \bar{T}_{sk} , HR, and M were unaffected by humidity until critical P_a ($P_{a crit}$) was reached above which M decreased and \bar{T}_{sk} and HR increased rapidly.

P_a crit decreased with clothing and decreasing velocity. T_e remained relatively constant throughout the tests. Sweating, discomfort and temperature sensations increased gradually with increasing P_a . Above P_a crit sweating and discomfort sensations accelerated markedly. Mass transfer coefficients and clothing vapor conductance factors were evaluated. Skin wettedness at P_a crit decreased from 74% at 0.1 m/sec to 35% at 2.4 m/sec.

15. **Berlyne, G. M.; Finberg, J. P. M.; and Yoran, C.:**

The Effect of β -Adrenoceptor Blockade on Body Temperature and Plasma Renin Activity in Heat-Exposed Man.

Br. J. Clin. Pharmac., vol. 1, 1974, pp. 307-312.

Annotation

Purpose. The effects of propranolol (5 mg i.v.) and practolol (10 mg i.v.) on rectal and skin temperatures, heart rate, blood pressure, plasma renin activity (PRA), and plasma renin substrate concentration (PRS) were investigated in men exercising in the heat.

Subjects. Twelve naturally heat-acclimatized men, aged 21-26 yr, on "ad libitum" food intake.

Conditions:

<i>DBT/WBT/RH</i>	<i>Air</i>	<i>kcal(m² • hr)</i>	<i>Regimen</i>
Week 1 25/18/50%	---	---	Bench stepping, 30 cm, 25 steps/min, 30 min.
Weeks 2, 3 45/25/17%	---	---	Bench stepping, 30 cm, 25 steps/min, 30 min.

Results and Conclusions.

1. Body temperatures were insignificantly affected by propranolol, while heart rate elevation in response to exercise in the heat was 21% lower than in the same subjects receiving saline. Diastolic blood pressure during exercise was elevated by propranolol.
2. The normal increase in PRA seen in heat exposure was suppressed by propranolol to levels seen when the same exercise was carried out at 25°C. Practolol did not affect the renin response to heat exposure.
3. PRS was not altered significantly by exercise or heat.
4. The results indicate that the increase in PRA seen in the heat is largely a result of increased sympathetic activity.

16. **Bonner, R. M.; Harrison, M. H.; Hall, C. J.; and Edwards, R. J.:**

Effect of Heat Acclimatization on Intravascular Responses to Acute Heat Stress in Man.

J. Appl. Physiol., vol. 41, 1976, pp. 708-713.

Authors' Abstract

The effects of a 185-min exposure to 48°C dry bulb, 33°C wet bulb, on intravascular volume and osmolarity and on intravascular electrolyte, aldosterone, and cortisol concentrations have been studied in five male subjects before and after acclimatization to heat. Changes in the hematocrit and plasma protein concentration indicated that a hemodilution occurred during the first 55 min of the heat exposures, and that this was followed by a hemoconcentration. Although these changes in

intravascular volume were not affected by acclimatization, the plasma volume after heat acclimatization was 6.7% greater than before. This increase in plasma volume was associated with an elevation in the ratio [Na]/[K]. However, since plasma osmolarity decreased the intravascular expansion could not be explained in terms of elevated electrolyte levels. Plasma aldosterone and cortisol levels were not affected by heat acclimatization, although both were elevated following exercise in the heat. It is concluded that the adrenal cortex is not an important factor in maintaining a state of heat acclimatization once a salt balance has been achieved.

17. Breckenridge, J. R.: and Goldman, R. F.:
 Solar Heat Load in Man.
J. Appl. Physiol., vol. 31, 1971, pp. 659-663.

Authors' Abstract

An electrically heated standing copper manikin, dressed in a standard tropical fatigue uniform, was exposed outdoors facing the sun to directly measure the solar heat loads predicted by the physical model reported previously by Roller and Goldman. This prediction model incorporates such factors as the amount of direct, diffuse, and terrain-reflected sunlight, solar angle, air movement, characteristics of the clothing, and area factors which are primarily a function of the man's position and orientation with respect to the sun. Experimental solar heat load was estimated as the difference, in the same environment, between manikin heat loss without sunlight and the actual measured dissipation outdoors; the former was calculated by use of clothing parameters established in the laboratory. Solar radiation components were measured directly with a sun-tracking pyrheliometer and shaded and unshaded total hemispheric radiometers. Agreement between predicted and experimental values of solar heat load, initially quite poor, was improved to within 4 W, average, by revising the equations, correcting the absorptance and transmittance factors for the uniform, and modifying the area factors applicable for each radiation component.

18. Burch, G. E.; and Ansari, A.:
 Artificial Acclimatization to Heat in Control Subjects and Patients With Chronic Congestive Heart Failure at Bed Rest.
Am. J. Med. Sci., vol. 256, 1968, pp. 180-194.

Annotation

Purpose. To determine whether patients with cardiac heart failure can be heat acclimatized.

Subjects. Four females, one male with congestive heart failure. Four females, one male as controls. Mean age: females, 66 and males, 46.

Conditions.

DBT/WBT/RH	Air	kcal/(m ² ·hr)	Regimen
32.2°/21.9/41%	---	---	Subjects arranged in pairs (1 control, 1 subject). Continuous supine rest until the end of tolerance as determined by the subject. Average heat exposure = 6.8 days (range = 4 to 12 days).

Results.

1. Oral body temperature remained elevated throughout the study for the subjects. In the controls there was an initial rise followed by a definite decline.
2. Respiration rate remained elevated throughout the study for the subjects. Variable results were seen in the controls, from no change in two to an initial rise followed by a decline in the remaining controls.
3. Pulse rates for the subjects showed no change, most likely due to the administration of a cardiac glycoside. In the controls an initial increase was followed by a decrease.
4. Blood pressure: no significant changes for either group.
5. Systemic venous pressure increased significantly and remained elevated for the subjects.
6. Fluid intake increased significantly for all except one subject.
7. Variable changes were seen in urine output.
8. Urinary Na and Cl decreased for the controls and three subjects, while in one subject Na and Cl excretion increased; in another subject no change was seen.
9. Urinary potassium excretion increased in all the subjects and in three controls. No change was seen in two controls.
10. Sweat rate increased for the controls, and dry skin prevailed for the subjects.
11. Initially, all the subjects and controls showed irritability at the onset of heat exposure. Although the controls gradually regained emotional stability, the subjects remained irritable and exhausted throughout their exposure.

Author's conclusion.

Patients with cardiac heart failure cannot depend on the process of acclimatization while living in tropical or subtropical climates. Measures such as air-conditioning and other means of facilitating heat loss are necessary for lessening the cardiovascular burden and improving cardiac function.

19. Cabanac, M.; Cunningham, D. J.; and Stolwijk, J. A. J.:
Thermoregulatory Set Point During Exercise: A Behavioral Approach.
J. Comp. Physiol. Psych., vol. 76, 1971, pp. 94-102.

Authors' Abstract

Response to a peripheral thermal stimulus has been shown to be an indicator of thermal status with respect to the thermoregulatory set point. The subjects were provided with a glove perfused with water, adjustable in temperature between 15°C and 45°C. The subjects were asked to maintain the glove temperature at the level they considered most pleasant. In response to environmental temperatures ranging from 15°-45°C, and to exercise at levels of 500 and 1,000 kg/min, the selected glove temperature ranged from 20°-40°C. The preferred glove temperature depended strongly on internal body temperature; it was affected to a lesser extent by mean skin temperature and not at all by exercise alone. The results suggest there is no change in thermoregulatory set point during exercise.

20. Chen, W. Y.; and Elizondo, R. S.:
Peripheral Modification of Thermoregulatory Function During Heat Acclimation.
J. Appl. Physiol., vol. 37, 1974, pp. 367-373.

Authors' Abstract

By applying a constant electrical stimulus to a forearm area in a cool environment before and after acclimation, it was demonstrated that, after acclimation, a greater sweat output was obtained by the stimulation. The postacclimation sweat increment observed during the local electrical stimulation in

the cold was identical to that observed under a constant whole-body heat stress. It was also demonstrated that the sweat increment was totally prevented by local treatment of low temperatures during heat acclimation. On the other hand, persistent local sweating, induced by electrical stimulation or by iontophoresis of ACh or Mecholyl, was not followed by a higher sweat output in the subsequent heat exposures. Repeated local heating also failed to produce a significant change in the sweat output. By blocking the nerve transmission to the forearm during whole-body heat exposures, it was shown that there is an equivalent amount of sweat increment both on the blocked and the unblocked arms. It was concluded that the increased sweat output following heat acclimation is due primarily to an increased sweating capacity of the sweat gland apparatus, which is modified only by exposing the whole body to heat. The phenomenon that acclimated men sweat at a lower body temperature is also explained in terms of peripheral modification in the thermoregulatory system.

21. Cleland, T. S.; Horvath, S. M.; and Phillips, M.:
Acclimatization of Women to Heat After Training.
Int. Z. Angew. Physiol., vol. 27, 1969, pp. 15-24.

Authors' Summary

During March and April three Caucasian women (ages 38, 22, 20) participated in a 3-week training program at 26°C dry bulb and 17°C wet bulb followed by 7 days of walking on a treadmill (3.5 miles/hr, 2.2 to 4.0% grade) for 1 hr each day in an environmental chamber (42.2°C dry bulb, 26.4°C wet bulb). 17 days later the subjects were tested again under the same hot conditions. For comparison, on the day after the 7-day acclimatization period and again after the terminal test, the subjects worked at equivalent work loads outside the chamber (26°C dry bulb, 17°C wet bulb). They wore shoes, socks, and cotton bathing suits. No subjects were able to complete the task on the first day, experiencing various degrees of discomfort, hypotension, and marked elevations of heart rate, rectal temperature, and skin temperature. Some degree of acclimatization was evident by the second day. After the seventh exposure they felt better, were able to work longer and had increased evaporative loss, with smaller elevations in heart rate and skin and rectal temperatures compared with those of the third day in the heat. The subjects exhibited an almost complete loss of heat acclimatization at the end of the subsequent 17-day period of no thermal stress.

22. Collins, K. J.; Brotherhood, R. J.; Davies, C. T. M.; Dore, C.; Hackett, A. J.; Imms, F. J.; Musgrove, J.; Weiner, J. S.; Amin, M. A.; el Karim, M.; Ismail, H. M.; Omer, A. H. S.; and Sukkar, M. Y.:
Physiological Performance and Work Capacity of Sudanese Cane Cutters With *Schistosoma mansoni* Infection.
Am. J. Trop. Med., vol. 25, 1976, pp. 410-421.

Authors' Abstract

Physiological tests of work performance and measurements of field productivity were made in 194 Sudanese cane cutters in order to study the effect of *Schistosoma mansoni* infection. The cane cutters were selected from two age ranges (16-24 and 25-45 yr) and subdivided into three clinical groups: not infected, infected with, and infected without clinical signs of hepatosplenomegaly. Men infected with *Schistosoma haematobium*, malaria (blood film) or with hemoglobin levels less than 10g/100 ml were excluded. There was a statistically significant ($P < 0.002$) higher mean hemoglobin concentration in those not infected, but the mean difference was less than 1 g/100 ml. Submaximal responses to exercise on a stationary bicycle ergometer, oxygen intake, ventilation, tidal volume, cardiac frequency, and estimated maximal aerobic power output calculated both in absolute terms and relative to lean body mass and leg volume were similar in the six groups of cane cutters. No significant differences were found in physique, body composition, or in the results of thermoregulatory function tests. The cane cutters were found to have little natural acclimatization to heat in terms of sweating capacity when compared with a group of fully acclimatized Sudanese soldiers. The

mean productivity (mean daily weight of cane cut per man) was significantly correlated with the individual's estimated maximum aerobic capacity determined in the laboratory, but not with the degree of *S. mansoni* infection. The noninfected group was less "efficient" (mean productivity oxygen intake) during cutting than the infected groups, but a larger proportion of the noninfected were in their first season of cutting. There was a positive correlation between the number of seasons' cutting experience and the individual's age, degree of infection, and mean productivity. Cane cutters studied in this investigation were a relatively fit, active population from whom the more seriously ill were excluded. These results do not, therefore, necessarily reflect the effects of *S. mansoni* on physiological work capacity and productivity of more static populations in areas of high endemicity.

23. Collins, K. J.; Few, J. D.; Forward, T. J.; and Giec, A.:
 The Plasma Glucocorticoid Response to Environmental Heat Stress.
J. Physiol. (London), vol. 22-23, 1967, pp. 33p-34p.

Annotation

Purpose. To study the pituitary-adrenal response to the stress of acute exposure to high environmental temperatures.

Subjects. Eleven subjects and 10 controls.

Conditions.

DBT/WBT/RH	Air	kcal/(m ² ·hr)	Regimen
46°/36°/53%	100 ft/min	----	Rest for 2 hr; four blood samples at ½-hr pre-exposure; 1 hr of exposure; ½ hr and 3½ hr post exposure, for 13 exposures. Five subjects. Tracer 1, 2- ³ H cortisol

Results.

	Mean Plasma Cortisol Concentration (S.E.) µg/100 ml			
	Pre	1 hr	½ hr Post	3½ hr Post
Heat (11 subjects)	12.0 ± 1.4	7.9 ± 1.1	21.3 ± 3.0	11.5 ± 2.2
Oral temp (°C) (11 subjects)	36.95 ± 0.12	38.30 ± 0.05	39.13 ± 0.06	----
Controls	9.9 ± 0.6	9.5 ± 0.9	8.1 ± 1.0	9.4 ± 1.8

1. Corticosterone values closely paralleled the cortisol values.
2. Plasma cortisol did not increase in two partially acclimatized subjects.
3. Plasma cortisol-³H concentration (mean).

	1-hr exposure	2-hr exposure
5 Subjects	-37%	-20%
Controls	-46%	-38%

Author's conclusion.

The increases in plasma cortisol and corticosterone concentrations, which occur when body temperature is elevated above 38.3°C, are primarily due to an increased adrenal secretion of these steroids.

24. Colquihoun, W. P.; and Goldman, R. F.:
Vigilance Under Induced Hyperthermia.
Ergonomics, vol. 15, 1972, pp. 621-632.

Authors' Abstract

Twelve highly practised subjects were tested in an ambient environment of 103°F (dry bulb), 93°F (wet bulb) on a 1-hr task of visual vigilance, after having performed, in the same environment, physical work which produced an ultimate rise in body-temperature of approximately 0°-4°F for every 10 min of continuous activity. The vigilance test was not carried out until the subjects had rested for at least 30 min after completion of the work; under these circumstances body-temperature remained elevated at a near constant level during the test. Contrary to results reported by earlier workers, no increase in the overall rate at which signals were detected was observed as a result of the raised body-temperature; however it was found that such an increase was observable if only those occasions when the subject indicated a high degree of confidence in the accuracy of his report following a signal presentation were scored as detections. Thus, there was, in effect, an increase in confidence with raised body-temperature, but no change in detection skill. This increase in confidence was accompanied by an increase in the frequency with which false reports were made; further analysis indicated that this reflected a change in the decision criterion used to determine whether a signal had been presented.

25. Consolazio, C. F.; Johnson, H. L.; Daws, T. A.; and Nelson, R. A.:
Energy Requirements and Metabolism During Exposure to Extreme Environments.
World Rev. Nutr. Diet., vol. 18, 1973, pp. 177-194.

Annotation

Purpose. To determine the effects of increased environmental temperature and increased relative humidity as they related to standardized energy expenditures and related parameters.

Subjects. Eleven males, ages 19-25.

Conditions.

DBT/WBT/RH	Air	kcal/(m ² · hr)	Regimen
1. 23.9/13.5/30%	---	---	5 days, daily exercise on bicycle ergometer for 30 min
2. 37.8/23.5/30%	---	---	10 days, same exercise beginning on third day
3. 37.8/32.6/70%	---	---	7 days, same exercise beginning on third day
4. 37.8/36-39/92-96%	---	---	7 days, same exercise beginning on third day

Results and conclusions.

Pulmonary ventilation rates, maximal heart rates, oxygen uptakes, and mean body temperatures showed significant increases over control values. The study confirmed the concept that under

conditions of low RH of 30% the oxygen uptakes of standardized physical work are significantly increased in a hot environment over the same work in a temperate environment. Significant increases at the higher temperature were observed in sweat rates (32.8%), pulmonary ventilation in ℓ/min (12.2%), maximal pulse rate (8.3%), oxygen uptakes in $ml/kg/min$ (15%) and in body temperature ($0.2^\circ C$). The daily energy requirements in a hot environment are increased. This is related to the increased requirement of the circulation in heat transport, increased action of the sweat glands, increased caloric loss due to sweat vaporization, and to the increase in body temperature.

26. Convertino, V. A.; Shvartz, E.; Haines, R. F.; Bhattacharya, A.; Sperinde, S. J.; Keil, L. C.; and Greenleaf, J. E.:
 Heat Acclimation and Water Immersion Deconditioning: Fluid and Electrolyte Shifts With Tilting.
Aerospace Med. Assoc. Preprints, 1977, pp. 13-14.

Annotation

Purpose. To compare the effects of exercise training in a cool environment and heat acclimation on resting plasma volume.

Subjects. Ten healthy males, 19-24 yr (five cool environment subjects, five hot environment subjects).

Conditions.

DBT/WBT/RH	Air	kcal/ $m^2 \cdot hr$	Regimen
Day 1			Plasma volume determination, Evans blue dye.
Days 2-9			Bicycle ergometer exercise, 2 hr/day, 75W ($\cong 50\%$ $\dot{V}O_2$ max)
24/30.4/50%	---	---	Cool group
40/30.4/50%	---	---	Hot group
Day 10			Plasma volume determination

Results.

1. Cool group plasma volume change (mean) = +385 ml (from 3.149 to 3.534 ml), $P < 0.05$.
2. Hot group plasma volume change (mean) = +552 ml (from 3.174 to 3.726 ml), $P < 0.05$.

27. Craig, F. N.:
 Evaporative Cooling of Men in Wet Clothing.
J. Appl. Physiol., vol. 33, 1972, pp. 331-336.

Author's Abstract

Men in groups of four, wearing two layers of clothing, were exposed once with and once without a dose of 2 mg of atropine sulfate to six conditions of assorted heat, humidity, exercise, and initial water content of the clothing. In varying degrees, depending on the conditions, the inhibition of sweating by atropine modified both the heat of evaporation (E) derived from the clothed weight loss and the heat storage (S) derived from the changes in rectal and mean skin temperatures. For the pooled control and atropine data in each condition, the progression of S on E had a slope that provided a measure of the cooling effect of an increment in evaporation from the clothing. For data

obtained during the period of exercise, the slope ranged from near unity in the dry windy condition, to near zero in the humid, still air conditions. The decrease in slope was associated with an unexpectedly small increase in water content of the clothing. Initial wetting of the clothing resulted in a substantial decrease in sweating, an effect attributed to the cooling of the skin. Under these conditions wet clothing prevents the elevation of body temperatures usually associated with the inhibition of sweating by atropine.

28. Craig, F. N.; Cummings, E. G.; Froelich, H. L.; and Robinson, P. F.:
Inhibition of Sweating by Atropine Before and After Acclimatization to Heat.
J. Appl. Physiol., vol. 24, 1969, pp. 498-502.*

Author's Abstract

In three groups of resting men, sweating and body temperatures were measured at environmental temperatures of 41° and 52°C. In group 1 (unacclimatized) in quiet air, sweating changed little during 7-hr exposures to heat, but at 52°C the body temperatures increased progressively. In group 2 (unacclimatized) in air moving at 1.5 m/sec, there were increases in sweating and body temperatures during 4-hr exposures such that there was no significant change in the slope of the line relating sweating and mean body temperature. The inhibitory effect of atropine sulfate on sweating, measured for 3 hr after intravenous injection, decreased at a rate of about 1% per min. In group 3, acclimatization to heat reduced the skin and rectal temperatures without a consistent change in the rate of sweating at 41° and 52°C; the relation between the dose of atropine sulfate infused intravenously at 41°C and the inhibition of sweating was the same before and after acclimatization. Under these conditions acclimatization did not appear to alter the response of the sweat glands to an added stimulus.

29. Dasler, A. R.; and Hardenbergh, E.:
Decreased Sweat Rate in Heat Acclimatization.
Federation Proc., vol. 30, 1971, p. 209.

Authors' Abstract

Heat acclimatization was studied in 8 human laboratory subjects (Grp I), and in 48 men flown in from 12 months' field work in the tropics (Grp II). Grp I had 10 consecutive days of incremental training (T) at 21°C DB and 15°C WB, with working metabolic rates (MR) maintained at 180 kcal/(m²·hr) the last 4 days; 10 days of heat acclimatization (HA) at 35°C DB and 31°C WB, MR 180 kcal/(m²·hr), then 9-10 weeks of exposure to HA conditions every fifth day (PA). Air velocity was 0.5 m/sec during all tests. Exposures were 110 min; 50 min work, 10 min rest, and 50 min work. Grp II subjects were tested under T conditions within 6 days of leaving the field, and the next day under HA conditions. Multiple measurements were recorded including 10 skin and 3 deep-body temperatures, heart rate, respiratory min vol, O₂ consumption, ECG, and blood pressures; and chemical analyses made of urine, blood, and sweat specimens. In Grp I, sweat rate (SR), determined by weight loss, increased with time during HA as shown by others. However, late in HA and continuing through PA, SR's decreased, paralleling the reduction seen in other physiologic parameters as strain decreased during acclimatization. In Grp II during the HA test, SR's in the most fit 13 were comparable to those of late PA Grp I, in 14 they were slightly higher, and in the least fit 21 they were near the maximal of early HA Grp I. We suggest that the reduced sweat rate seen after prolonged exposure to a hot-humid climate is an indication of improved physiologic efficiency in advanced heat acclimatization.

*Same as: Craig, F. N.; Cummings, E. G.; and Froehlich, H. L.: Inhibition of Sweating by Atropine and Scopolamine before and after Acclimatization to Heat, *Edgewood Arsenal Tech. Rept.* EATR 4285, June 1969.

30. Dasler, A. R.; Karas, S.; Bowman, J. S.; and Hardenbergh, E.:
Adverse Effects of Supplementary Sodium Chloride on Heat Adaptation.
Federation Proc., vol. 32, 1973, p. 336.

Authors' Abstract

The physiological effects of excessive supplementary NaCl during simultaneous training and heat acclimatization were studied. Eight human test subjects were evaluated at three different levels of dietary NaCl (normal = 15 g/day, "A"; normal + 15 g/day, "B"; normal + 7.5 g/day, "C") while attempting to induce simultaneous training and acclimatization for 10 consecutive days at each NaCl level. "A", "B" and "C" were randomized with 6 weeks of sedentary living on "A" between each treatment. Exposures were at 35°C DB, 31°C WB, V 0.5 m/sec for 110 min/day (50 min work, 10 min rest, and 50 min work) with work metabolic rate at 180 kcal/(m²·hr). Multiple measurements included: 10 skin and 3 deep body temperatures; heart rate (HR); respiratory min vol; O₂ consumption; ECG; blood pressures (BP); nine calculated cardiovascular factors; sweat rate determined by corrected weight loss; and biochemical analyses of urine, blood, and sweat. Whole body K⁺ was monitored daily. "B" and "C" produced cardiovascular impairment (depressed HR, BP, total vascular resistance, and "T" wave height; increased "R" wave height and "K" sounds), decreased optimal work capacity and metabolic efficiency, impaired heat acclimatization, progressive loss of total body K⁺, and increased output of Na⁺, K⁺, Cl⁻, Ca⁺⁺ and PO₄⁻⁻⁻. It is concluded that excessive supplementary NaCl should be avoided to prevent adverse physiological effects in man.

31. Davies, C. T. M.; Barnes, C.; and Sargeant, A. J.:
Body Temperature in Exercise.
Int. Z. Angew. Physiol., vol. 30, 1971, pp. 10-19.

Authors' Summary

The tympanic temperature (T_{ty}), sweat rate (S), and oxygen intake ($\dot{V}O_2$) of a male athlete and non-athlete have been measured during work of 1-hr duration with arms, legs, arms and legs combined on a stationary bicycle ergometer, and during walking and running on motor-driven treadmill, before and after habituation to work and acclimation to heat.

The results showed that during the first few occasions of repeated exercise in the sedentary subject, but not in the athlete, the relationship of T_{ty} was curvilinear rather than linear ($p < 0.001$). At end of the period of habituation in both subjects T_{ty} was more closely related to relative (percent $\dot{V}O_2$ max) rather than absolute work load. However, following acclimatisation the reverse was true. Through the period of the investigation in the nonathlete T_{ty} for a given $\dot{V}O_2$ of 2.5 l/min fell by 1.01°C and sweat rate and body heat conductance rose, but the directly measured $\dot{V}O_2$ max increased by only 5%. In the athlete, all these parameters were fairly constant. In both subjects T_{ty} was independent of muscle mass involved in the exercise.

The reasons underlying these changes are discussed. It is suggested that the training of man's thermoregulatory and maximum aerobic power mechanisms are not necessarily interdependent and that the rise in T_{ty} is due to the proportional nature of central nervous control mechanisms and ability of the body to dissipate rather than to produce heat.

32. Dill, D. B.; Horvath, S. M.; Van Beaumont, W.; Gehlsen, G.; and Burrus, K.;
Sweat Electrolytes in Desert Walks,
J. Appl. Physiol., vol. 23, 1967, pp. 746-751.

Authors' Abstract

The rate of sweating in desert walks at 80 or 100 m/min and the concentrations of sodium, potassium, and chloride in sweat have been studied in 31 school boys, the same number of school girls, in several men, and in 2 women. Findings indicate that the rate of sweating under such conditions even up to an ambient temperature of 42°C depends on body surface, metabolic rate, and ambient temperature, not on sex or age. The sweat produced is all evaporated; there is equal water economy irrespective of age and sex. Earlier unpublished findings on concentrations of electrolytes in sweat from the hand and from the body of men and boys are reported. Deductions based on sweat collected from a gloved hand may be invalid. In particular, the concentration of potassium may be 3 times higher than in sweat from the entire body surface. An individual exhibits a wide range in composition of sweat depending on the internal and external environment. Also there is a wide intraindividual range in the same external environment and at the same metabolic rate.

33. Dill, D. B.; Soholt, L. F.; and Oddershede, I. B.;
Physiological Adjustments of Young Men to Five-Hour Desert Walks.
J. Appl. Physiol., vol. 40, 1976, pp. 236-242.

Authors' Abstract

Seven young men undertook a desert walk of 30 km at a rate of 100 m/min. Six finished; the seventh stopped after 24 km. Each satisfied his thirst with cool tap water each hour. Periodic observations included metabolic rate, blood pressure, heart rate, rectal and skin temperature, body weight, and volume of water drunk. Hand sweat was collected each hour and body sweat residues on the skin were collected at the end of the walk. Subjective reports revealed portents of breakdown: aching muscles, painful joints, hot or blistered feet, hunger, and boredom. Cardiovascular adjustment and temperature regulation maintained tolerable conditions. The volumes of water evaporated by the 5-hr walkers were about the same. Wet bulb temperatures were below 25°C; all sweat evaporated and was available for temperature regulation. The volume of water drawn from body reserves was closely correlated with concentration of chloride in body sweat; the volume of water that satisfied thirst maintained osmotic pressure.

34. Drinkwater, B. L.; Denton, J. E.; Kupprat, I. C.; Talag, T. S.; and Horvath, S. M.;
Aerobic Power as a Factor in Women's Response to Work in Hot Environments,
J. Appl. Physiol., vol. 41, 1976, pp. 815-821.

Authors' Abstract

Twelve young women, athletes ($n = 6$) and nonathletes ($n = 6$), walked on a treadmill at loads equivalent to $\sim 30\% \dot{V}O_2$ max for two 50-min periods in three environments: (1) 28°C, 45% RH, (2) 35°C, 65% RH, and (3) 48°C, 10% RH. There were no differences between groups in rectal temperature, heart rate, evaporative heat loss, or mean skin temperature at 28° or 35°C or during the first work period in the 48°C environment. However, a significantly lower cardiac output (Q) and stroke volume (SV) observed for nonathletes by the 46th min of work at 48°C may explain why no nonathletes were able to complete a second hour of work while four of six athletes successfully finished the period. It appears that in conditions of severe heat stress (48°C) athletes were able to maintain a cardiac output sufficient to meet the metabolic requirements and the large increase in peripheral blood flow for a longer period of time than nonathletes.

35. Drinkwater, B. L.; Denton, J. E.; Raven, P. B.; and Horvath, S. M.: Thermoregulatory Response of Women to Intermittent Work in the Heat. *J. Appl. Physiol.*, vol. 41, 1976, pp. 57-61.

Authors' Abstract

Seven women worked intermittently in three randomly ordered sessions at 75% V_{O_2} max at three temperatures, 28°C (45% RH), 35°C (65% RH), and 48°C (10% RH) and recovered in a cool environment (22°C) after each 6-min work period. Although T_{re} was higher in each successive work period, the ambient temperature had no effect on the cardiovascular or respiratory responses or on ΔT_{re} . In all conditions, SV decreased with time with a concomitant increase in HR to maintain Q . A fall in mean blood pressure from the initial to final measurement was due entirely to a decrease in diastolic pressure. The final T_{re} for these women was approximately equal to that previously reported for men working continuously for 1 hr under conditions equivalent to time-weighted average of the thermal and metabolic loads during work and recovery in this study.

36. Drinkwater, B. L.; Raven, P. B.; Horvath, S. M.; Gliner, J. A.; Ruhling, R. O.; Boldman, N. W.; and Taguchi, S.: Air Pollution, Exercise, and Heat Stress. *Arch. Environ. Health*, vol. 28, 1974, pp. 177-181.

Annotation

Purpose. To compare the effects of the interactions of heat stress and air pollutants upon the aerobic power of smokers and nonsmokers.

Subjects. 20 young males; 10 were smokers, 10 nonsmokers.

Conditions.

DBT/WBT/RH	Air	kcal/(m ² · hr)	Regimen
25°C and 35°C	—	—	Double blind study. Subjects breathed filtered air, carbon monoxide (50 ppm), peroxyacetyl nitrate (0.27 ppm), or a combination of the two (50 ppm CO + 0.27 ppm PAN). Treadmill testing to maximum aerobic power

Results and conclusions.

Heat stress more effectively limited the aerobic capacity of the men than either single pollutant or combination of the two ($P < 0.05$). The length of the treadmill walk was less for both groups ($P < 0.01$) under all pollutant conditions.

37. Dukes-Dobos, F. N.; Buskirk, E. R.; Bar-Or, O.; and Henschel, A.:
Effect of Dehydration on Tolerance to Exercise in Heat as Influenced by Acclimatization.
Physiologist, vol. 13, 1970, p. 184.

Authors' Abstract

Subjects (Ss) were 10 college students, 4 lean and 2 obese males and 2 lean and 2 obese females. Each subject was exposed in a climatic chamber to successive 20-min exercise and 20-40-min rest periods in 6-7 hr until Ss reached a fluid loss of approximately 2.7% or 4.2% of body weight. Exercise consisted of treadmill walking at 3 miles/hr at 0-5-10% grade, respectively, and of step tests corresponding in intensity to that of the treadmill walks. Each S was exposed twice to each of the two conditions. On one occasion the Ss received complete fluid replacement; on the other no fluid intake was permitted. The climatic conditions were kept in all sessions within the limits of $38.0\text{-}39.5T_a$ and $20.0\text{-}24.1T_{wb}$. All but two lean-male Ss were moderately acclimatized to the same test conditions by three previous exposures for about 4 hr each. All Ss had higher heart rates (HR) and rectal temperatures (T_{re}) when dehydrated. In the test series with 2.7% fluid loss there was no difference in HR and T_{re} elevation between male and female or lean and obese Ss. In the 4.2% fluid loss series the obese Ss had higher elevations in HR and T_{re} than the lean Ss. Unacclimatized lean male Ss' increments in HR were the highest. Although absolute values of HR and T_{re} were higher in the female Ss, elevation of these parameters due to dehydration was greater in the male Ss.

38. Fein, J. T.; Haymes, E. M.; and Buskirk, E. R.:
Effects of Daily and Intermittent Exposures on Heat Acclimation of Women.
Int. J. Biometeor., vol. 19, 1975, pp. 41-52.

Authors' Abstract

Twelve women, who differed in physical condition and body size, were heat-acclimated utilizing either a daily or intermittent (every third day) exposure pattern in an environmental chamber. The women walked for 100 min at 5.2 km/hr up a 2.5% grade on a motor-driven treadmill. Climatic chamber conditions were $46.5^{\circ}\text{C }T_a$, $24.5^{\circ}\text{C }T_{wb} \pm 0.5^{\circ}\text{C}$. Although individual acclimation varied, significant reduction in heat strain was observed in all subjects, e.g., the ability to complete the assigned task with increasing ease, a decrease in working heart rate, a decrease in rectal temperature rise, a decrease in mean skin temperature, an increase in sweat rate, an increase in evaporative rate, and a decrease in heat storage. The pattern of heat exposures, daily or every third day, had no discernible effect on the rate of heat acclimation. The highly conditioned subjects showed less physiological strain, particularly during the first few heat exposures, and maintained some relative advantage throughout the series of 10 exposures. Body size, in the range studied, appeared to exert little influence on the amount of thermal strain.

39. Finberg, J. P. M.; and Berlyne, G. M.:
Renin and Aldosterone Secretion Following Acute Environmental Heat Exposure.
Israel J. Med. Sci., vol. 12, 1976, pp. 844-847.

Annotation

Purpose. To investigate the various factors affecting aldosterone secretion in heat-exposed men.

Subjects. Twelve subjects (23-28 yr).

Conditions.

<i>DBT/WBT/RH</i>	<i>Air</i>	<i>kcal/(m²·hr)</i>	<i>Regimen</i>
50°/25°/13%	----	----	Five subjects
25°/18°/52%	----	----	Five subjects
50°/25°/13%			1 hr sitting rest followed by bicycle ergometer exercise of 450 kpm-min ⁻¹ for 30 min Subjects by choice did not drink water
			Five additional subjects (three from original groups and two additional) performed same heat tests with and without prior injection of propranolol (5 mg, i.v.)

Results.

1. No differences between control and heat groups in rectal temperature increases (+0.6°C).
2. Plasma renin activity increased significantly in the heat (+6.10 ng AI·ml⁻¹·h⁻¹) but not in control tests.
3. Aldosterone concentration increased by 18.2 ng/dl in the heat and 40 ng/dl in the control subjects.
4. Plasma cortisol showed no significant change during the 25°C exercise, and variable changes in the heat exercise.
5. Following propranolol injection heart rate was, in all cases, lower on conclusion of exercise in the heat. Variable results were seen for plasma renin activity and aldosterone concentration.

40. Finberg, J. P.M.; and Berlyne, G. M.:

Modification of Renin and Aldosterone Response to Heat by Acclimatization in Man.
J. Appl. Physiol.: Respirat. Environ. Exercise Physiol., vol. 42, 1977, pp. 554-558.

Authors' Abstract

Plasma renin activity (PRA) and aldosterone concentration (PA) increased in eight men following a brief (30-40 min) heat exposure (50°C dry bulb, 25°C wet bulb) with light work. Sweat loss was less than 1% body weight. Plasma cortisol concentration was unchanged or decreased. In four subjects, a standard heat test was repeated in winter and summer (natural acclimatization). The increase in PRA and PA following heat exposure was less in summer than in winter. Four other subjects were artificially acclimated by daily work periods of 90 min at 50°C for 7 days (artificial acclimation). Heat-induced elevation in PRA was considerably reduced by artificial acclimation, although post-heat PA was reduced in only two of the four subjects. The small degree of sweat loss under the conditions of these experiments shows that circulating renin and aldosterone levels are increased in the heat even when a significant sodium deficit is not incurred.

41. **Finberg, J. P. M.; Kaplanski, Y.; and Berlyne, G. M.:**
Renin and Aldosterone Secretion Following Heat Exposure in Man — Relationship to $\dot{V}O_2$ max and Artificial Acclimatization.
Israel J. Med. Sci., vol. 12, 1976, p. 1530.

Authors' Summary

Plasma renin activity (PRA) was determined in a group of 14 young men following a standard heat exposure. Subjects exercised on a bicycle ergometer at 40% of estimated maximal aerobic capacity ($\dot{V}O_2$ max) for 30 min at an environmental temperature of 50°C (20% relative humidity). Heart rate averaged 133 ± 13 (SD) beats/min on completion of the test, and rectal temperature averaged $37.4^\circ \pm 0.25^\circ$ (SD) C. PRA varied between 3.1 and 25.4 ng angiotensin I/ml/hr. No relationship was found between PRA and $\dot{V}O_2$ max or heart rate. Thus, renin secretion in the heat did not appear to be related to the degree of physiological strain when work load was set at a constant proportion of $\dot{V}O_2$ max. In a separate experiment, six men were acclimatized to heat by daily exposures to 50°C for 7 days with exercise on the bicycle ergometer at 40 to 50% $\dot{V}O_2$ max, following a prior conditioning period of 7 to 10 days in which they carried out the same work daily in a cool environment. PRA following heat exposure averaged 9.5 ± 4.4 (SD) ng angiotensin I/ml/hr on day 1 and 8.0 ± 4.7 ng/ml/hr on day 7. Plasma aldosterone concentration averaged 22.6 ± 8.5 (SD) ng/100 ml on day 1 and 25.5 ± 8 ng/100 ml on day 7. Changes in physiological strain as well as in PRA induced by acclimatization were of a much lower amplitude in the present study than in a previous work with untrained individuals. It is concluded that part of the improvement in physiological and endocrinological response to heat following acclimatization in untrained men may be related to the effects of physical training.

42. **Finberg, J. P. M.; Katz, M.; Gazit, H.; and Berlyne, G. M.:**
Plasma Renin Activity After Acute Heat Exposure in Nonacclimatized and Naturally Acclimatized Man.
J. Appl. Physiol., vol. 36, 1974, pp. 519-523.

Authors' Abstract

Plasma renin activity (PRA) in residents of a semidesert zone was determined before and after exposure to high ambient temperature (50°C dry bulb, relative humidity 30%) for 90 min, with walking on a level treadmill at 4.7 km/hr. These conditions caused a pronounced elevation of PRA, which was greater in the winter months than at the end of summer. No change occurred in PRA following the same treadmill walk at 25°C. The increase in PRA on heat exposure was not related to the degree of sweat loss, but was linearly correlated with final heart rate. The degree of physiological strain produced was greater in winter than in summer. The increase in PRA was partially, but not completely, suppressed by replacing water and sodium chloride in advance of loss. Increased PRA in heat is suggested to be a result of (1) sweat sodium loss, and (2) renal nerve stimulation, which reflects the general visceral vasoconstriction compensating for extensive peripheral vasodilatation. Additionally, reduction in splanchnic blood flow could lead to a reduced hepatic clearance of renin, resulting in a passive elevation of PRA.

43. **Fortney, S.; and Senay, L. C., Jr.:**
The Effects of a Modest Training Program on the Responses of Females to Work in a Hot Environment.
Federation Proc., vol. 36, 1977, p. 512.

Authors' Abstract

Nine females exercised for 45 min at 40% $\dot{V}O_2$ max on one day in a cool (20°C dry bulb, 30% relative humidity) and on another day in a hot (45°C dry bulb, 30% relative humidity) environment. The exercises were repeated both pre and post ovulatory. The subjects then underwent 3 weeks of training consisting of pedalling a bicycle ergometer for 90 min/day at a load sufficient to maintain heart rate at 140 beats/min. The pre and post ovulatory standard work tests were then repeated. This report is concerned only with the heat exposures. Training was accompanied by an 11% increase in $\dot{V}O_2$ max and a 7% increase in blood volume, T_{re} and heart rates after the 45 min heat exposure were less while sweat rates were slightly greater after the training period. Unlike male subjects, training did not alter the behavior of most of the measured blood constituents. With similar treatment, male subjects have been shown to gain protein within the vascular volume while the females tended to lose protein during the heat exposure but gained protein within a 30-min rest at room temperature (24°C). Before and after training, the female subjects suffered a 13-14% decrease in plasma volume during exercise in heat which was regained within 30 min of end of exercise. There were no significant differences noted between pre and post ovulatory results. As for males, training increased the sensitivity of the sweating mechanism.

44. **Foster, K. G.; Ellis, F. P.; Dore, C.; Exton-Smith, A. N.; and Weiner, J. S.:**
Sweat Responses in the Aged.
Age, Ageing, vol. 5, 1976, pp. 91-101.

Annotation

Purpose. To study the sweating responses in aged males and females.

Subjects. Young females (20-35 yr), young males (18-65 yr), aged females (70-94 yr), aged males (70-92 yr).

Conditions.

DBT/WBT/RH	Air	kcal/(m ² ·hr)	Regimen
28-30° / - / -	---	---	Subjects were heated by placing their feet and legs in a water bath at 43.5°C. Sweat rate measured at sites on chest, back, upper abdomen, neck (trunk) and forehead, forearm, thigh, back of head (peripheral)

Results and conclusions.

Males

1. Significant reduction in the sweat rate per gland in the aged subjects.
2. There were more "no responses" at the periphery than on the trunk in the aged.
3. The threshold for sweating onset was significantly decreased at all sites in the aged.
4. The relative decrease in the maximum sweat rates for the aged males was more pronounced on the forearm than the chest.

5. The maximum sweat rates produced on both the chest and forearm were significantly lower in the aged.

Females

1. N.S.D. between chest/trunk thresholds in the young men and women.
2. Maximum chest sweat rates were slightly lower ($P>0.05$) in the young women than in the young men.
3. N.S.D. between the number of active sweat glands on the chest in the young men and young women.
4. Forearm sweat rates were significantly decreased in the young women.
5. Sweating responses in the old women were very poor or nonexistent.

45. **Fox, R. H.; Crockford, G. W.; and Löfstedt, B.:**
A Thermoregulatory Function Test.
J. Appl. Physiol., vol. 24, 1968, pp. 391-400.

Authors' Abstract

Ten Cincinnati students were studied during summer months using a mobile thermoregulatory function test. The test was designed to measure the normal levels of deep-body and skin temperatures, the temperature levels at sweat onset, the sweating response to a given elevation of deep-body temperature, the rate of sweat suppression, and the deep-body to skin temperature gradient. The results are compared with measurements on British soldiers before and after artificial acclimatization during winter and early spring. Sweat rates in the students corresponded to the acclimatized British level. The rate of sweat suppression was significantly less than for either the acclimatized or unacclimatized British subjects. The significance of this finding is discussed. Deep-body and skin temperatures observed in the neutral environment corresponded more closely with the unacclimatized than the acclimatized British level, but at sweat onset skin temperatures were similar to the acclimatized British value. A comparison of two tests on eight subjects indicates that the test has a high degree of reproducibility.

46. **Fox, R. H.; Even-Paz, Z.; Woodward, P. M.; and Jack, J. W.:**
VIII. A Study of Temperature Regulation in Yemenite and Kurdish Jews in Israel.
Phil. Trans. Roy. Soc. London, Series B., vol. 266, 1973, pp. 149-168.

Authors' Abstract

Temperature regulation has been studied in 34 Yemenite Jews and 33 Kurdish Jews, including both men and women, using a standard thermoregulatory function test based on an air conditioned bed. The subjects were first tested at the Negev Institute for Arid Zone Research in the hot summer of 1968 and a proportion were then retested 6 months later in the cooler winter weather.

The results reveal no differences between the Kurdish Jews and Yemenite Jews in thermoregulatory function. The women of both ethnic groups had much lower sweat rates, stored more heat before sweating was initiated, and had higher skin temperatures at sweat onset than the men. These sex differences are discussed in relation to previous studies on the differences in temperature regulation between European men and women.

Both males and females sweated less in the winter than in the summer. In the summer experiments, sweating capacity corresponded to the level found in partially heat acclimatized Europeans, whereas in the winter experiments the level for the Israeli Jews was significantly lower than that for unacclimatized European controls tested in Britain.

47. Fox, R. H.; Löfstedt, B. E.; Woodward, P. M.; Eriksson, E.; and Werkström, B.: Comparison of Thermoregulatory Function in Men and Women. *J. Appl. Physiol.*, vol. 26, 1969, pp. 444-453.*

Authors' Abstract

Thermoregulation in 21 young men and 21 young women was studied by a mobile standard function test at Lund in Sweden; the results are analyzed together with comparable measurements on a control group of British male subjects before and after heat acclimatization. The principal differences between the two sexes at Lund concerned the sweating mechanism; the women had a much higher sweat onset threshold, lower sweating capacity, and no significant rate of sweat suppression. In addition, a difference was found in the relationship of ear-to-rectal temperatures in the two sexes. The comparisons with the control group show that most of the differences between the sexes are similar to those that exist between acclimatized and unacclimatized men. The results are discussed in relation to previous studies and the hypothesis is put forward that many of the differences between the sexes previously reported can be simply explained in the same way; also, there are logical reasons for expecting women to be less heat-acclimatized than men when both sexes are living in identical climatic conditions.

48. Francesconi, R.; Maher, J.; Bynum, G.; and Mason, J.: Recurrent Heat Exposure: Effects on Levels of Plasma and Urinary Sodium and Potassium in Resting and Exercising Men. *Aviat. Space Environ. Med.*, vol. 48, 1977, pp. 399-404.

Authors' Abstract

Heat acclimatization was induced in a group of healthy young men by walking on a treadmill (5.6 km/hr, 49°C/27°C dry/wet bulb, 90 min/day, 7 days) and confirmed by observing significantly reduced final rectal temperatures and heart rates on the seventh day of exercise in the heat. A second group of men, paired for maximal oxygen consumption and body weight, remained sedentary under identical environmental conditions. Although the mild exercise combined with the severe heat conditions induced significant hyperkalemia ($p < 0.02$, minimal significance) on both the first and final days, there did occur an attenuated response with significantly ($p < 0.01$) reduced plasma K+ after 45 min on the seventh day when compared with first day levels. No significant inter- or intragroup differences in plasma Na+ levels were found although the Na+ content of 24-hr urine samples showed that men exercising in the heat retained an increased ability to conserve Na+, while sedentary individuals consistently displayed increased excretion of Na+. Thus, we concluded that even the mild exercise described herein effected hyperkalemia at each sampling time, but the level of hyperkalemia was attenuated after acclimatization, and while Na+ was conserved in the exercising men, no such adaptive processes occurred in sedentary individuals.

49. Francesconi, R. P.; Maher, J. T.; Bynum, G. D.; and Mason, J. W.: Recurrent Heat Exposure: Enzymatic Responses in Resting and Exercising Men. *J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 43, 1977, pp. 308-311.

Authors' Abstract

Heat acclimatization was induced in a group of healthy male test subjects by repetitive treadmill walking (5.6 km/hr, 49°/27°C dry/wet bulb, 90 min/day, 7 days). A second group of men, paired for maximal O₂ consumption and body weight, remained sedentary under identical environmental conditions. Total plasma protein increased significantly after 45 min ($P < 0.05$) and 90 min

*Same as: Fox, R. H., and B. Löfstedt. A comparison of thermoregulatory function in men and women. *J. Physiol.* 197:44P-45P, 1968.

($P < 0.025$) of exercise on the first day of heat exposure, yet after 7 days no increments occurred. Even after heat acclimatization was achieved (day 7), plasma levels of creatine phosphokinase increased during the 90-min walk in the heat (time 0 vs. 90, $P < 0.025$) as was also the case on day 1 ($P < 0.05$). Levels of lactate dehydrogenase, glutamate-oxaloacetate transaminase, and glutamate-pyruvate transaminase were not significantly affected by exercise in the heat either before or after heat acclimatization. No correlations could be drawn between base-line enzyme levels and state of physical conditioning.

50. Gagge, A. P.; and Gonzalez, R. R.:

Physiological and Physical Factors Associated With Warm Discomfort in Sedentary Man.
Environ. Res., vol. 7, 1974, pp. 230-242.

Authors' Abstract

Thermal discomfort, defined as an expression of man's dissatisfaction with his thermal environment and measured by the magnitude estimates method, has been observed: (1) during humidity transients, when the ambient temperature is held constant at 32°, 36°, and 40°C; (2) during transients of the ambient temperature at constant relative humidity; and (3) during transients caused by both radiant heat and humidity while the ambient temperature is held at 32°C. The best single physiological index of thermal discomfort, especially without the presence of thermal radiation, is skin wettedness, which is defined as the ratio of the observed skin evaporative heat loss to the maximum evaporative capacity of the environment for a completely wet skin surface. Radiant heat (RH), by raising mean skin temperature by 1.5°-2°C, causes the rate of rise of thermal discomfort with skin wettedness to increase. A biophysical effective temperature (ET*), defined as the temperature of a black enclosure at 50% RH, in which man would exchange the same heat by radiation, convection, and evaporation as in the observed environment, correlates well with thermal discomfort regardless of the complexity of the thermal environment. The discomfort, caused by skin wettedness itself, may be attributed to the increasing strain caused first by the internal drive to secrete regulatory sweat, and second by the increased peripheral resistance at the skin surface.

51. Gisolfi, C. V.:

Work-Heat Tolerance Derived From Interval Training.
J. Appl. Physiol., vol. 35, 1973, pp. 349-354.

Author's Abstract

Six healthy college students attempted a 100-min walk on a level treadmill at 5.6 km/hr in dry heat (48.9°/26.7°C db/wb). After this initial heat-tolerance test (HTT) the men trained 30 min/day, 5 days/week in a cool (21°C) temperature-controlled environment. The workouts raised the men's rectal temperatures (37.8°-39.4°C), elicited pronounced sweating (0.21-0.56 kg), and increased $\dot{V}O_2$ max 15%. The HTT was repeated after 4, 8, and 11 weeks of training, after which the men were acclimated to the heat by repeating the HTT daily for 8 days. Performance time (PT), rectal temperature (T_{re}), mean skin temperature, heart rate (HR), and sweat rate during the first HTT averaged 74 min, 39.2°C, 38.2°C, 186 beats/min, and 638 g/(m²·hr). Corresponding mean values for the second HTT were 92 min, 39.3°C, 37.4°C, 186 beats/min, and 661 g/(m²·hr); for the third 95 min, 38.9°C, 37.0°C, 148 beats/min, and 645 g/(m²·hr); for the fourth 95 min, 38.8°C, 37.3°C, 142 beats/min, and 629 g/(m²·hr); and following heat acclimation 100 min, 38.0°C, 36.2°C, 124 beats/min, and 688 g/(m²·hr). Using the ratio of terminal T_{re} /PT as an index of heat tolerance, 8 weeks of interval training in a cool environment produced 50% of the total adjustment resulting from heat acclimation.

52. **Gisolfi, C. V.; and Copping, J. R.:**
Thermal Effects of Prolonged Treadmill Exercise in the Heat.
Med. Sci. Sports, vol. 6, 1974, pp. 108-113.

Authors' Abstract

Six trained men 21-38 yr old ran 19-29 km (1.5 to 2.5 hr), approximately 75% of their $\dot{V}O_2$ max, on a level treadmill in the heat ($33.5^\circ/21.5^\circ\text{C}$ db/wb, wind velocity 36 m/min). Every 20 min while running they (a) drank 200 ml of 10°C water, (b) drank 200 ml of water at core body temperature, or (c) sponged their faces, arms, and trunks for 2 min with a towel soaked in 10°C water. In another series of experiments each subject (d) hydrated 30 min before the run by drinking 1 liter of water (e) hydrated and performed (a) above, and (f) hydrated and performed (b) above. Rectal temperature (Tre) and body weight loss (WL) were determined every 20 min and metabolism at 45 min of running. Terminal Tre after (a) through (f) averaged 39.1° , 39.3° , 39.9° , 39.7° , 39.1° , and 39.3°C respectively. During a control run the corresponding mean Tre was 39.9°C . In a 66.7-kg man with a body weight/surface area (BW/SA) ratio of 37.5 and running at 74% of his $\dot{V}O_2$ max, Tre rose $0.4^\circ\text{C}/1\%$ WL with increasing WL's greater than 2.0% of his initial body weight regardless of the intervention imposed. In another subject weighing 70 kg with a BW/SA ratio of 38.8 and running at 83% of his $\dot{V}O_2$ max, Tre rose $0.49^\circ\text{C}/1\%$ WL over the entire range of WL's. These data indicate that (1) the rise in Tre during prolonged work in the heat is related to the %WL incurred; (2) consuming 1 liter of warm or cold water on the run is more effective in preventing a marked rise in Tre than drinking an equal volume of water 30 min before the run; and (3) sponging the upper body with a cold towel while running is ineffective in preventing a marked rise in Tre.

53. **Gisolfi, C.; and Robinson, S.:**
Relations Between Physical Training, Acclimatization, and Heat Tolerance.
J. Appl. Physiol., vol. 26, 1969, pp. 530-534.

Authors' Abstract

This study was designed to determine effects of strenuous physical training on men's tolerance for work in heat. Five healthy, untrained young men, wearing only shorts, shoes, and socks, attempted a 90-min walk (avg time 86 min) on a treadmill (MR 4-5 met) in heat (50°C db, 27°C wb). After this heat tolerance test the men performed 6 weeks (5 March-23 April) of intensive interval training in T-shirt, shorts, shoes, and socks on an indoor track, alternating with strenuous handball or basketball games 1 hr daily 5 times/week in a cool environment (21°C). The workouts raised the men's rectal temperatures markedly (38.4° - 39.7°C) and elicited pronounced sweating (0.47-1.44 kg). The training period was followed by a second work-heat exposure, in which all men completed the 90 min and had none of the symptoms of syncope shown by the majority in the initial exposure. Rectal and mean skin temperatures averaged 39.6° and 37.8°C , and heart rates averaged 168 beats/min at the end of the initial exposure; corresponding mean values for the posttraining heat tests were 38.7°C , 36.8°C , and 144 beats/min. Mean sweat rate per degree increase in rectal temperature above 37°C increased 50%. Interval training indoors improved the heat tolerance of the men significantly, but did not fully acclimatize them for work in the heat.

54. **Givoni, B., and Goldman, R. F.:**
Predicting Rectal Temperature Response to Work, Environment, and Clothing.
J. Appl. Physiol., vol. 32, 1972, pp. 812-822.

Authors' Abstract

Formulas, based on a biophysical model, have been developed which predict the time pattern of rectal temperature response to work, environmental conditions, and clothing properties. Three separate formulas appear to be required for the patterns of change in rectal temperature, one during rest

in the heat, another for the rising stage during work, and a third for the recovery after cessation of work. The formulas involve the metabolic heat production, ambient climatic conditions (air temperature, vapor pressure, and velocity), and the total thermal resistance and evaporative coefficient of the clothing. Related formulas permit computation of the following components: (1) metabolic heat production (with subject weight, speed, and grade of walking or running and load carried as factors); (2) total thermal resistance and evaporative coefficient for clothing as functions of the ambient air velocity and the additional air motion produced by the working subject (i.e., effective air speed); and (3) dry heat exchange with the environment and maximum evaporative capacity derived from such clothing coefficients. Good agreement has been found between the prediction of these formulas and several experimental series at the U.S. Army Research Institute of Environmental Medicine, as well as with studies elsewhere.

55. Givoni, B.; and Goldman, R. F.:

Predicting Heart Rate Response to Work, Environment, and Clothing.
J. Appl. Physiol., vol. 34, 1973, pp. 201-204.

Authors' Abstract

Formulas are presented for the prediction of the heart rate response to work, environment, and clothing. These formulas, derived from rectal temperature responses, predict the dynamic response pattern of heart rate with time of exposure, not only for a constant activity and environment but also with varying activity, environment, and clothing during an exposure. The accuracy of the prediction has been checked by comparison with experimental results from several studies at different laboratories and under a wide range of conditions. The predicted value is usually well within one standard error of the actual experimental mean response of a small group of heat-acclimatized subjects (e.g., n = 8).

56. Givoni, B.; and Goldman, R. F.:

Predicting Effects of Heat Acclimatization on Heart Rate and Rectal Temperature.
J. Appl. Physiol., vol. 35, 1973, pp. 875-879.

Authors' Abstract

Despite numerous studies on acclimatization to hot-dry or hot-wet conditions, no generally applicable formulation of the effects of acclimatization has been attempted. This paper develops a general model describing the changes in heart rate and rectal temperature, as a function of days of exposure to work in the heat, for any temperature and humidity combination. The model describes three components of the effects of heat acclimatization: (1) a decrease in the initial level of rectal temperature with acclimatization; (2) a decrease in the equilibrium level which rectal temperature and heart rate approach with work; and (3) a widening gap between nonacclimatized and fully acclimatized subjects with duration of work in heat with respect to both responses. The data from a study on 24 subjects working at 49°C, 20% RH, 1.4 m/sec wind, were fitted as a function of the number of days of previous work in the heat, with an estimate of 0.5 day of acclimatization loss for each day of nonexercise in the heat intervening. The predictive model fits this data closely, and has been more generally validated by comparing its predicted responses to the extensive data reported by Wyndham's group for acclimatized (23 days) and unacclimatized subjects under saturated conditions and by other investigators under hot-dry conditions.

57. Gilner, J. A.; Raven, P. B.; Horvath, S. M.; Drinkwater, B. L.; and Sutton, J. C.: Man's Physiologic Response to Long-Term Work During Thermal and Pollutant Stress. *J. Appl. Physiol.*, vol. 39, 1975, pp. 628-632.

Authors' Abstract

Metabolic, temperature, and cardiorespiratory responses of 19 healthy males, age range 18-30 yr for one group and 40-55 yr for another, were studied during 210 min submaximal work at 35% \dot{V}_{O_2} max. The subjects were exposed to four different pollutant gas mixtures at two different temperatures, 25°C and 35°C (relative humidity 30%). The four gas mixtures were filtered air (FA), 50 ppm carbon monoxide in filtered air (CO), 0.24 ppm peroxyacetyl nitrate in filtered air (PAN), and a combination of all three mixtures (PANCO). In the CO exposure, the heart rate was significantly greater than that observed during FA conditions ($P < 0.05$). Metabolic and thermoregulatory responses to long-term work were not different in the various pollutant environments. Significant decreases in stroke volume and increases in heart rate were observed during the course of the 25°C exposures with no alteration in cardiac output. Heart rates were higher during 35°C exposures while cardiac output remained at the same level with a consequent further reduction in stroke output.

58. Gonzalez, R. R.; Pandolf, K. B.; and Gagge, A. P.: Physiological Responses and Warm Discomfort During Heat Strain. *Arch. Sci. Physiol.*, vol. 27, 1973, pp. A563-A571.

Annotation

Purpose. To study the acclimatization process during 6 days of heat exposure in humid and dry hot environments to compare estimates of warm discomfort to physiological strain during exercise in the heat.

Subjects. Six males, 22 yr, mean weight 72 ± 5.5 kg, mean body surface area $1.9 \pm 0.12 \text{ m}^2$, mean \dot{V}_{O_2} max 50 ml/kg.

Conditions.

DBT/WBT/RH	Air	kcal/(m ² ·hr)	Regimen
40°C / - / 20-90%	---	---	6 days bicycle ergometry at 25% \dot{V}_{O_2} max 20 min sitting rest, 40°C 15 min exercise, RH grad. increase from 20% to 90% 15 min exercise, 40°C, 90% RH 6 weeks later: same regimen at constant 20% RH, 40°C

Results and conclusions.

1. Subject discomfort to dry heat (control) decreased over 6 days of exercise; whereas discomfort continually increased throughout exercise in humid heat.

	<i>Humid</i>	<i>Dry</i>
HR	Continual rise throughout exercise on all 6 days	Day 1, equilibrium at 20 min Day 6, equilibrium at 15 min
T _{es}	Continual rise throughout exercise on all 6 days	Day 1 equilibrium at 20 min Day 6 equilibrium at 10-15 min
T _{sk}	Continual rise throughout exercise on all 6 days	Equilibrium on day 6 at 10-15 min
Forearm sweat rate	Significant increase by sixth day exercise, with continual rise throughout exercise on day 1 and day 6	No difference between day 1 and day 6; gradual increase in rate of sweat throughout exercise on both days
Total sweat rate	Significantly higher on day 6; on both days increase for first 5 min, with continual decrease thereafter	Higher sweat rates on day 6 than on day 1. Equilibrium reached at 20-25 min of exercise on both days

2. Increases in discomfort with humidity are somehow related to physiological responses, with the limitations on secretion and evaporation of sweat particularly important in the cause of discomfort. As skin temperature increases, deep-body temperature also rises. The resulting sweat rate increase, but lack of evaporation in humidity, produces no cooling satisfaction. Warm discomfort may never show adaptation.

59. Gonzalez, R. R.; Pandolf, K. B.; and Gagge, A. P.:
 Heat Acclimation and Decline in Sweating During Humidity Transients.
J. Appl. Physiol., vol. 36, 1974, pp. 419-425.

Authors' Abstract

Six unclothed male subjects exercised (25% \dot{V}_{O_2} max) on a bicycle ergometer in constant 40°C ambient temperatures with high air movement, while ambient vapor pressure (P_a) was increased from 12 to 49 Torr. Experiments were conducted on six consecutive days. Whole-body, local forearm sweating, and local chest conductance were recorded. Increasing humidity raised heart rate (HR), esophageal (T_{es}), and skin (T_{sk}) temperatures to identical maximal levels each day. Total and local sweating increased progressively during each daily exposure. Excessive skin wetting during the last half of the humidity experiments depressed whole body sweating. Plots of forearm sweating versus T_{es} showed increasing sweat secretion rates at lower T_{es} (postacclimation) with no change in slope (gain). Chest conductance, plotted as a function T_{es} , was 25-30% higher postacclimation. Six weeks later, the same experiments were repeated at a low constant P_a . Acclimation to dry heat, without sweat suppression, increased sweat gland function by increasing the proportional control constant (gain), which governs T_{es} for whole body sweating.

60. **Greenleaf, J. E.; Bosco, J. S.; and Matter, M., Jr.:**
Orthostatic Tolerance in Dehydrated, Heat-Acclimated Men Following Exercise in Heat.
Aerospace Med., vol. 45, 1974, pp. 491-497.

Authors' Abstract

The effect of dehydration – taken alone and in combination with exercise in the heat – on orthostatic tolerance was studied in four well-conditioned men before and after heat acclimation. Compared with normal hydration responses, there was no change in the orthostatic responses when the subjects were 2 to 3% dehydrated before or after acclimation. Decreased orthostatic tolerance was evident after the combined stresses of dehydration plus exercise in the heat, and was severe after heat acclimation; three of the four subjects had to be lowered before the sixth minute of tilting. The decreased tolerance after acclimation was attributed to a less sensitive vasoconstrictive system conditioned for heat dissipation by the repeated heat exposure. Although heat acclimation is usually a necessary treatment for optimal functioning in the heat, under the special conditions of assumption of the orthostatic position, heat acclimation appears to be a liability.

61. **Greenleaf, J. E.; Castle, B. L.; and Ruff, W. K.:**
Maximal Oxygen Uptake, Sweating, and Tolerance to Exercise in the Heat.
Int. J. Biometeor., vol. 16, 1972, pp. 375-387.

Authors' Abstract

The purpose of this experiment was to determine if tolerance to exercise in the heat is related to maximal oxygen uptake ($\text{max } \dot{V}_{O_2}$) and sweating. Seven men with $\text{max } \dot{V}_{O_2}$ between 42 and 66 ml/(min·kg) underwent one 2-hr exposure at $24^\circ\text{C } T_q$ while working on a bicycle ergometer at mean rel \dot{V}_{O_2} of 28% (mean $\dot{V}_{O_2} = 1.23 \text{ l/min}$). In the hot exposures the high capacity subjects had maximal sweat rates of 800 to 1,000 g/(m²·hr) while the lower capacity men sweated 300 to 400 g/(m²·hr). These differences in sweating were not related to neuromuscular stimuli, \dot{V}_{O_2} (metabolic rate), T_{re} , ΔT_{re} , \bar{T}_s , $\Delta \bar{T}_s$ or tolerance time. Tolerance to exercise in the heat was not related to maximal \dot{V}_{O_2} capacity when the subjects worked at the same relative load, in spite of large differences in sweating. These results question the importance of the rate of sweating for predicting work performance in hot environments.

62. **Hale, H. B.; Williams, E. W.; and Ellis, J. P., Jr.:**
Cross-Adaptation in Military Trainees in a Hot Climate.
Aerospace Med., vol. 43, 1972, pp. 978-983.

Authors' Abstract

To test for cross-adaptation in heat-acclimated men, physiologic tests were performed on groups of military trainees at Lackland AFB, Texas, where great care is taken in summer to ensure the development of high degrees of heat tolerance. Control data were obtained from trainees who were studied in winter, a time of temperate climatic conditions. Baseline determinations were made with the subjects (14-18 per group) remaining at complete rest for 4 hr, with ambient temperature at 25°C . Other groups of this same size experienced either hyperoxia alone, cold alone, heat alone, hyperoxia plus cold or hyperoxia plus heat. The hyperoxia (which was induced by breathing 100% O₂ at 1 atm ambient pressure) was a research tool used for the purpose of either enhancing or blocking responses to mild thermal changes (either a 10° increase or a 10° decrease from 25°C). The thermal changes ("pulses") were initiated at the beginning of the third hour of the 4-hr test period and lasted only an hour, after which there was a 1-hr recovery period. Urine specimens collected at the end of the test period were analyzed for potassium, sodium, magnesium, inorganic phosphate, uric acid, urea, and creatinine. Analyses of variance revealed seasonal variation for magnesium ($P < 0.01$), potassium

($P < 0.01$), and Na/K ratio ($P < 0.01$) and urea ($P < 0.05$). Temperature sensitivity was found for magnesium ($P < 0.05$), potassium ($P < 0.01$) and uric acid ($P < 0.05$), and oxygen-sensitivity was established on the basis of phosphorus ($P < 0.01$) and magnesium ($P < 0.05$). Differences in the metabolic response patterns of the trainees studied in summer and winter strongly suggest that heat adaptation led to positive cross-adaptation.

63. **Harrison, M. H.:**
 Plasma Volume Change During Work in a Hot Environment,
J. Physiol. (London), vol. 245, 1975, pp. 102P-103P.

Annotation

Purpose. To study the plasma volume changes during exercise in the heat and recovery from that exercise.

Subjects. Six males not acclimatized to heat.

Conditions.

DBT/WBT/RH	Air	kcal/(m ² ·hr)	Regimen
42°C/35°C/63%	---	---	Exercised on bike ergometer for 50 min at 25% of estimated aerobic capacity

Results and conclusions.

1. Plasma protein shows no correlation to changes in plasma volume.
2. Plasma osmolarity increases and then plateaus during mild exercise.
3. Changes in red cell volume (hematocrit and hemoglobin levels) provides an "acceptable" measure of plasma volume changes.

64. **Harrison, M. H.:**
 Intravascular Volume and Electrolyte Changes With Acclimatization to Heat in Man.
J. Physiol. (London), vol. 258, 1976, p. 31P.

Annotation

Purpose. To study the relationship of changes in plasma volume and electrolyte concentration on control of body temperature during heat acclimation.

Subjects. Five males.

Conditions.

DBT/WBT/RH	Air	kcal/(m ² ·hr)	Regimen
48°C/33.5/36%	---	---	13 programs of heat exposure; 48°C dry bulb and 36% RH Rest seated for 155 min, then exercised at 50W for last 30 min

Results.

1. No relationship between T_{ac} and plasma volume changes.
2. Plasma osmolarity correlated with T_{ac} .
3. $[Na^+]$ levels increased.

Conclusion.

1. Increased Na^+ levels cannot account for increased plasma volume in terms of tonicity since plasma osmolarity decreased.
2. Plasma osmolarity may influence thermoregulation.

65. **Harrison, M. H.; Edwards, R. J.; and Leitch, D. R.:**
Effect of Exercise and Thermal Stress on Plasma Volume.
J. Appl. Physiol., vol. 39, 1975, pp. 925-931.

Authors' Abstract

Six male subjects exercised for 50 min at 25% (light exercise) and 55% (moderate exercise) of their estimated aerobic capacities in environments of 42°C dry bulb, 35°C wet bulb and 30°C dry bulb, 24°C wet bulb, respectively. Alterations in the hematocrit, hemoglobin, and plasma protein concentrations, and in the activity of an injected aliquot of isotopically labeled albumin were each used to calculate the percentage change in plasma volume occurring during exercise and recovery. Changes in each measure were consistent with a reduction in plasma volume during exercise and a return to preexercise levels during recovery. There was no significant difference between the measures when exercising in the heat, but during the more severe exercise in the cooler environment disproportionate changes in protein, hematocrit, and hemoglobin were observed. Disproportionate changes were also seen during the recovery phase, when the hematocrit and hemoglobin concentration indicated a more rapid return of the plasma volume to preexercise levels than did either the plasma protein concentration or albumin activity. During moderate exercise and recovery there was a 1% decrease in red cell volume. It is concluded that exercise accelerates the rate of protein movement from extra-vascular compartments to the intravascular compartment, leading to elevated plasma protein levels during recovery, which favor the return of water to the intravascular space. Hemoglobin concentration is considered to be the most reliable measure of plasma volume change during exercise.

66. **Haymes, E. M.; Buskirk, E. R.; Hodgson, J. L.; Lundgren, H. M.; and Nicholas, W. C.:**
Heat Tolerance of Exercising Lean and Heavy Prepubertal Girls.
J. Appl. Physiol., vol. 36, 1974, pp. 566-571.

Authors' Abstract

Twelve girls, ages 9 to 11 yr, were exposed to four different environments to determine their tolerance of exercise in dry heat. The subjects, who were divided into lean and heavy groups on the basis of body density, walked on a treadmill at 4.8 km/hr, 5% grade for 1 hr at 21.1°, 26.7°, 29.4°, and 32.2°C T_{eff} . In the warmest environment, 32.2°C T_{eff} , lean subjects had higher rectal temperatures (T_{re}) and greater changes in T_{re} during the session (ΔT_{re}) than heavy subjects. Only two girls completed 60 min of exercise at 32.2°C T_{eff} . Little difference between the two groups was observed in the other environments except that the lean girls had higher mean skin temperatures. Compared with adults, the girls appeared to have more heat exchange through radiation and convection, more evaporative heat loss, and a higher heat production per unit mass. It was concluded that prepubertal girls, like prepubertal boys, have less tolerance for exercise in the heat at 32.2°C T_{eff} than adults.

67. Hénane, R.:
La dépression sudorale au cours de l'hyperthermie contrôlée chez l'homme. Effets sur le débit et les électrolytes sudoraux. (Sweat Depression During Controlled Hyperthermia in Man. Effects on Sweat Rate and Sweat Electrolyte Content.)
J. Physiol. (Paris), vol. 64, 1972, pp. 147-163.

Author's Summary

1. Sweating was obtained in nine healthy men at rest by exposure to a hot surrounding which induced a controlled hyperthermia. The skin and body temperatures were constant throughout the experiment. The sweat production was estimated by measuring the subject weight loss. Sweat was also collected on the body to measure its electrolyte concentration. Each man was exposed to the hot surrounding for 1 hr daily during 9 consecutive days.

2. The sweat secretion decreased with time during the hour of hyperthermia (sweat depression). With high initial sweat rates, the sweat depression appeared quickly, 15 min or less after the start of hyperthermia. Its intensity was proportional to the initial sweat rate.

3. This depression is more important in a hot and humid environment than in a hot and dry one. The abrupt change from a hot-humid condition to a hot-dry one partially suppresses this depression, which therefore appears to be a rapid reversible phenomenon.

4. The sweat depression does not affect the evaporative efficiency inasmuch as it acts essentially upon the excretory, nonevaporative fraction of dripping sweat, which does not intervene in heat dissipation.

5. The excretion of sweat electrolytes Na^+ , Cl^- , K^+ , is not constant. During the hour of controlled hyperthermia Na^+ excretion is increased, K^+ decreased, and Cl^- unchanged. The alteration of Na^+ excretion, which is independent of the sweat rate, may result from the hormonal action of ADH.

6. There are also long-term variations of the sweat electrolytes excretion. From the first to the fourth day of heat exposure, the excretion of the electrolytes varies passively, i.e., increasing with sweat rate (acclimatization effect). From the fifth day on the excretion decreases for these three ions, whereas the sweat rate continues to increase. This second phase of sweat dilution may result from a delayed action of a hormonal mechanism for salt retention.

68. Hénane, R.; and Bitel, J.:
Changes of Thermal Balance Induced by Passive Heating in Resting Man.
J. Appl. Physiol., vol. 38, 1975, pp. 294-299.

Authors' Abstract

Heat acclimatization has been induced in 12 resting healthy men by 90-min exposure to 45°C dry bulb and 24% relative humidity for 9 successive days. The most significant results observed were (1) increased sensitivity of sweating with marked quickening of sweat measured; and (2) decreased rate of body heat storage associated with a lower rectal temperature at end of exposure, as follows: 14.07 ± 1.58 ($\text{W}\cdot\text{hr}$)/kg before and 9.39 ± 1.69 afterward for body heat storage; $37.55^\circ \pm 0.15^\circ\text{C}$ before and $36.99^\circ \pm 0.24^\circ\text{C}$ afterward for rectal temperature. In contrast, no significant changes were observed in the final sweat rates, mean skin temperatures, or the heat conductance between the body interior and skin surface. The quickness of the heat dissipation process caused by both increased sensitivity of sweating and lower internal body temperature is the major factor in achieving a thermal balance and a decreased body heat content after acclimatization.

69. Hénane R.; and Valaty, J. L.:
Thermoregulatory Changes Induced During Heat Acclimatization by Controlled Hyperthermia in Man.
J. Physiol. (London), vol. 230, 1973, pp. 255-271.

Authors' Summary

1. Heat acclimatization has been carried out by a controlled hyperthermia procedure, and induced thermoregulatory changes have been investigated for nine fit young men.
2. During the experiments two types of thermal responses became apparent. The subjects tolerating the rise in the central temperature during hyperthermia displayed a marked improvement of their sweating capacity and their sweating performances, and a parallel shift towards lower body temperatures of the curves relating sweat rate to tympanic, rectal and mean skin temperatures.
3. This shift occurred without any change in the slope, that is without any change in the gain of the central control system. It was accompanied by a concomitant shift of the threshold of sweating onset, so that for a given central temperature there was a higher sweat rate following treatment.
4. The sweat decline appeared late in tolerant subjects. This decline was early in the intolerant subjects and appeared as early as the first day of heat treatment. Moreover, these subjects displayed no increase of sweat output with repeated sessions of heat treatment.
5. The core-periphery temperature gradient measured during the cooling stage did not change in the tolerant subjects when acclimatization had developed. This gradient increased in the intolerant subjects because deep temperature decreased slowly whilst skin temperature decreased rapidly. The core of intolerant subjects retained the stored heat and dissipated it slowly. The tolerant subjects seemed on the contrary to display in the same conditions increased tissue conductance enabling rapid dissipation of the stored heat.

70. Henschel, A.; Cole, M. B.; and Lyczkowskyj, O.:
Heat Tolerance of Elderly Persons Living in a Subtropical Climate.
J. Gerontology, vol. 23, 1968, pp. 17-22.

Authors' Summary

The ability of elderly persons to tolerate a combined stress of heat and work was studied in a group of 38 females (average age 69 yr) and 62 males (average age 72 yr). The stress consisted of 70 min of exposure to 92°F dry-bulb and 82°F wet-bulb temperatures with intermittent work on a bicycle ergometer. Each S was tested both at the end of the summer and again at the end of the winter seasons. These elderly persons were able to tolerate the work-in-heat stress without evidence of excessive physiological strain.

The physiological responses to the stress were lower at the end of the summer season than at the end of the winter. The reduced evidence of strain during the summer testing indicates that these elderly persons retained the ability to become heat acclimatized in response to exposure to the hot summer weather characteristic of the area. On both the summer and winter tests, the females had a higher work pulse rate and oxygen consumption per kilogram of body weight than did the males.

71. Höfler, W.:
Changes in Regional Distribution of Sweating During Acclimatization to Heat.
J. Appl. Physiol., vol. 25, 1968, pp. 503-506.

Author's Abstract

Regional distribution of sweating was examined with the method of Weiner during acclimatization experiments of 18-35 days' duration. Four subjects exposed to humid heat showed an increase in the relative sweating of the limbs from initial values of 28-42% to 34-54% of the total sweating rate. In two subjects exposed to dry heat an increase from 40 to 43% was not significant. Two subjects with high initial values of 48-55% of the total sweating rate did not exhibit a further increase during acclimatization. A shifting of sweat distribution toward the limbs implies a better utilization of large surface areas with most favorable evaporation conditions.

72. Höfler, W.; and Hermann, I.:
Hizeakklimatisation bei Ichthyosis Simplex. (Heat Acclimatization in a Case of Ichthyosis.)
Äerztl. Forsch., vol. 24, 1970, pp. 81-85.

Authors' Abstract

A 46 year-old male subject suffering ichthyosis vulgaris, and showing bad performance when working under heat stress was submitted to a 12 days' acclimatization procedure (36°C , 69% RH, 2 X 50 min work on an ergometer bicycle at 7 ppm/sec). Sweat rate in the first working shift increased from 180 to 406 g/hr, in the second shift from 360 (third day) to 540 g/hr. Pulse rate decreased from 167 to 134/min (first shift) and from 161 to 142/min (second shift), rectal temperature from 39.2° to 37.7° and from 38.9° to 37.9°C , respectively.

It is demonstrated that a considerably higher sweat rate—as compared with normal subjects—was necessary to achieve a certain degree of evaporation, but this disproportion was ameliorated, relatively, in the course of acclimatization. The increase in sweat output, which in normal skin only enlarges the wetted area, enhanced in the patient's skin also the wettability.

The increment of sweating was most pronounced on the trunk; the trunk's contribution to total sweat output rose from 39.5 to 49.5%, thus reaching nearly normal values.

73. Höfler, W.; Ladipoh, J.; and Laaser, U.:
Beziehung zwischen Schweißmenge, Verdunstung und Körpertemperatur bei der Akklimatisierung in künstlichem feuchtheissem Klima. (Relation Between Sweat Rate, Evaporation Rate and Body Temperature in Acclimatization to an Artificial Tropical Climate.)
Int. Z. Angew. Physiol., vol. 27, 1969, pp. 34-42.

Authors' Summary

One male subject living 5 weeks continuously in an artificial hot-humid climate (36.5°C , 69% RH, the temperature at night being lowered to 31°C) worked daily 4 hr on a bicycle ergometer at 8 mfp/sec. Estimation of heat balance was derived from climate, core temperature, skin temperature, and metabolism. A decrease of heat storage during acclimatization was not significant. Core temperature and skin temperature decreased by 1°C . Heat gain from the environment therefore increased by 59 kcal/4 hr, this increase being compensated by an increase of evaporative heat loss (87 kcal/4 hr). Sweat rate during the first 3 days was 1.4 evaporation rate in the first working period, falling continuously in 4 hr to 1.1 evaporation rate. Evaporation, however, was kept constant by increasing body temperature. After acclimatization sweat rate was about 2.4 evaporation rate and remained constant—as evaporation—for at least 4 hr. The sweat rate/core temperature- and evaporation/core temperature-relationship after acclimatization was steeper, and both curves were shifted to lower

body temperature. From the relation of sweat rate and evaporation rate, respectively, to body temperature and to maximum evaporation the conclusion is drawn, that the skin had not been fully wetted before acclimatization, and sufficient evaporation could be reached only by an increase of body (skin) temperature. Fully wetted skin, however, is achieved by the excessive increase of sweat rate during acclimatization. Then sufficient evaporation is possible at a lower and only slightly rising body temperature.

74. Hori, S.; Ihzuka, H.; and Inouye, A.:
Physiological Responses to Whole Body Bath and Hot Air Exposure With Special Reference to Assessment of Heat Tolerance.
Jap. J. Physiol., vol. 25, 1975, pp. 567-573.

Authors' Abstract

In studies of heat tolerance in man, a hot bath has been sometimes used as heat stress. Sweating under water is not used for dissipation of heat; thus, assessment of heat tolerance with hot water bath methods is expected to be considerably different from that with the hot air method. Applying our indices methods for assessment of heat tolerance, therefore, the hot-water-bath method as a heat tolerance test was compared with that of exposure to hot air. The physiological responses to heat and heat tolerance were examined in eight male college students in a hot air environment and in hot water at 39°C and 39.5°C. After staying for 30 min in a climatic chamber with a temperature of 30°C dry bulb and 70% relative humidity, sweating in air was produced by immersion of both legs to just below the knees into a 42°C water bath with stirring. Each subject was then immersed into a hot water bath of 39°C or 39.5°C up to the neck for 30 min after 30 min rest. Experiments on another group of six male students were made with hot bath of 38°C. Sweat rate and sweat Na concentration in an air environment were fairly well correlated with those in hot baths, while increase in rectal temperature was poorly correlated with that in hot baths. When assessed with our indices method, heat tolerance evaluated in an air environment did not always run parallel with that in hot baths. Such a discrepancy in heat tolerance assessed in hot air and in hot water appears to be explained chiefly by unusefulness of sweat produced under water for cooling the body in hot baths.

75. Hori, S.; Inouye, A.; and Ihzuka, H.:
Indices and Sweating Patterns for the Assessment of Heat Tolerance.
Jap. J. Physiol., vol. 24, 1974, pp. 263-275.

Annotation

Purpose. To propose an alternative method of determining heat tolerance by utilizing a simple index involving relative factors of increase in rectal temperature and sweat and salt losses.

Subjects. Forty male students, ages 18-25.

Authors' results.

1. Two kinds of indices are proposed for the assessment of heat tolerance. Indices *I* and *S* are calculated utilizing the following equations:

$$I = \sqrt{A^2 + B^2 + C^2}, \quad S = B / \sqrt{A^2 + C^2}$$

where: *A* = relative water loss

B = relative rise in body temperature

C = relative salt loss

during the sweating test.

2. Ohara's sweating type method, representing a relation between local sweat rate and sodium concentration in sweat, was modified by using salt loss in place of sodium concentration. Sweating patterns were classified into U, N, and T Types in the Q (salt loss)- V (peak sweat rate) plane. Type U corresponds to Ohara's Type 1, the least heat tolerant, and Type T corresponds to Ohara's Type 4, the most heat tolerant.

3. Results obtained with the authors' method and Index I coordinated well. Type U showed the highest value of Index I , Type T the lowest; this suggests that the lower value of Index I indicates a greater heat tolerance.

4. The three-type method and Index S revealed no significant correlation, which suggests that Index S is not a measure to be applied to heat tolerance. It was discussed that Index S may be utilized as an index to represent effectiveness of homeostatic mechanism to thermal regulation.

5. Ohara's four sweating types and Index I showed no significant correlation. Thus, the three-type method appears to be a more satisfactory tool for examining heat tolerance.

76. Hori, S.; Inouye, A.; Ihzuka, H.; and Yamada, T.:

Study on Seasonal Variations of Heat Tolerance in Young Japanese Males and Effects of Physical Training Thereon.

Jap. J. Physiol., vol. 24, 1974, pp. 463-474.

Authors' Summary

1. Physiological responses to heat and heat tolerance were examined in summer and winter on 39 male college students. After having been in the chamber for 30 min, sweating was induced by immersing both legs up to the knees for 90 min in a water bath at 42°C in a climatic chamber maintained at 30°C with 70% relative humidity.

2. Heat tolerance was assessed by heat strain caused by a certain heating condition. The heat strain was represented by a combination of relative increase in rectal temperature (B) plus relative water loss (A) and salt loss (C). Indices I and S were defined, as reported previously, as $(A^2 + B^2 + C^2)^{1/2}$ and $B/(A^2 + C^2)^{1/2}$, respectively, to assess the heat tolerance.

3. Sweating reaction in summer was characterized by a relatively smaller salt loss despite a greater water loss, and the rise in rectal temperature was less in summer than in winter.

4. The mean value of Index I showed no significant seasonal differences, being 0.24 in both seasons. The mean values of Index S in summer and winter were 0.81 and 1.42, respectively, the difference being statistically significant.

5. The mean value of Index I for the athlete group, which included college sportsmen, was significantly lower than that of the nonathlete group (0.21 and 0.27, respectively, irrespective of the seasons); no significant difference was found in Index S between the two groups.

6. Despite the lack of seasonal variation of Index I , the magnitude of individual I showed a good correlation with heat tolerance as judged by the sweating type, in a classification system originally developed by Ohara.

7. Based on these results, applicability of the indices for the assessment of individual heat tolerance is discussed.

77. **Hori, S.; and Yoshimura, H.:**
Comparison of Changes in Sweating Reaction Between Short-Term and Long-Term Heat Acclimatization.
New Trends in Thermal Physiology, Y. Houdas and J. D. Guieu, eds., Masson, Paris, 1978, pp. 184-186.

Annotation

Purpose. To compare sweating reaction and physiological responses to heat between two groups of residents in Okinawa in summer and in winter.

Subjects. Fifteen young males born and raised in Okinawa and 11 young males residing in Okinawa for less than 2 yr.

Conditions.

DBT/WBT/RH	Air	kcal/(m ² ·hr)	Regimen
30°/25.5°/70%	---	---	Subjects sat for 30 min, whereupon sweating was induced by immersion of both legs into a stirring water bath of 42°C for 30 min

Results.

1. Those born and raised in Okinawa showed in both seasons significantly higher sweat volumes, significantly lower Na sweat concentrations, and significantly lower sweat onsets.
2. Sweat volume for the subjects who had moved to Okinawa was considerably greater in summer than in winter; for those born in Okinawa a lesser seasonal variation in sweat volume was seen.
3. NSD in increase of heart rate and rise in rectal temperature between the two groups in both seasons.

Conclusion.

1. Unacclimatized subjects sweat more readily and profusely in short-term heat acclimatization.
2. Sweating patterns of unacclimatized subjects are more readily affected by changes in ambient temperature, and long-term acclimatized subjects sweat more slowly and in less volume.

78. **Horstman, D. H.; and Horvath, S. M.:**
Cardiovascular and Temperature Regulatory Changes during Progressive Dehydration and Euhydration.
J. Appl. Physiol., vol. 33, 1972, pp. 446-450.

Authors' Abstract

Three nonacclimatized male subjects were exposed at 48°C, WVP 7.0, for 7 hr, once each with (euhydration) and without (dehydration) fluid replacement. Dehydration resulted in a 3.6% decrease in body weight, a 13.6% decrease in plasma volume, and an 8.0% decrease in blood volume; no significant changes occurred during euhydration. Whole-body evaporative rates and local sweating from thigh and abdomen were maintained at significantly higher levels during euhydration than during dehydration. Initially, forearm and calf blood flows exhibited substantial increases, which were maintained during euhydration, but which declined to control levels if dehydration was allowed to

occur. Rectal, tympanic, mean skin, and mean body temperatures increased continuously after 90 min of dehydration; a constant level was attained and maintained during euhydration. Storage of body heat, as calculated from the heat balance equation, was more than twice as large during dehydration as during euhydration. It was concluded that temperature regulatory failure occurred during dehydration and was related to inadequate evaporation and reduction of peripheral blood flow.

79. Horstman, D. H.; and Horvath, S. M.:
Cardiovascular Adjustments to Progressive Dehydration.
J. Appl. Physiol., vol. 35, 1973, pp. 501-504.

Authors' Abstract

Nine male subjects who had not been heat-acclimatized were exposed at 48°C, vapor pressure 7.0 mm Hg, for 7 hr without fluid replacement. Body temperatures, metabolism, evaporative losses, cardiac output, and peripheral blood flow (calf and forearm) were measured. Changes in thermal balances during the heat exposure of these nine subjects were similar to those observed in a previous study of three men. Cardiac output increased twofold and remained at that level during the entire period of dehydration; calf and forearm flows increased to their peak values after 1 hr, remaining at or below the peak level for 3-4 hr, after which they steadily declined toward control levels. The interrelationships between the different patterns of central and peripheral blood flows during progressive dehydration are discussed.

80. Kamon, E.:
Acclimation Process by Daily Exercise Stints at Temperature Conditions Followed by Short Heat Exposures.
Aviat. Space Environ. Med., vol. 47, 1976, pp. 20-25.

Author's Abstract

In order to improve the conventional procedures for heat acclimation by making the process shorter and more efficient, four daily regimens of 30 min of exercise under temperate ambient conditions (22°C) followed by a 30-min walk (5.6 km/hr) under hot dry ambient conditions (50°/25°C, T_{db} / T_{wb}) were administered to three groups of subjects. The respective exercise part for each group was as follows: (1) 30 min of descent on a laddermill (negative work); (2) 30 min of ascent on a laddermill (positive work), and (3) 15 min of descent followed by 15 min of ascent on the laddermill. The four daily regimens of exercise and heat exposure were followed by four consecutive daily walks of up to 120 min in dry heat. A fourth control group was not subjected to the special acclimation regimen, but underwent the eight daily conventional acclimation procedures. Acclimation was judged by the increase in tolerance time (T) for the walk in the heat and decrease in heart rate (HR) rectal temperature (T_{re}) and mean skin temperature (\bar{T}_{sk}). Partial acclimation was observed after the 4 days of the regimen for the three experimental groups and the 4 days of the conventional procedure on the fourth control group. The final state of acclimation was apparent on the eighth day for all four groups. When the partial acclimation after the 4-day regimen was compared to the final state of acclimation, the following improvements were observed: 90% increase in T; 72% decrease in HR; 56% decrease in T_{re} , and 45% fall in \bar{T}_{sk} . These improvements were similar to those observed after the 4 days of the conventional treatment on the control group as well as to those reported by others.

81. Kamon, E.; and Avellini, B.:
Physiologic Limits to Work in the Heat and Evaporative Coefficient for Women.
J. Appl. Physiol., vol. 41, 1976, pp. 71-76.

Authors' Abstract

Ten heat-acclimated females exercised seminude on a treadmill at 30% $\dot{V}O_2$ max ($M = 15.2 \text{ W/m}^2$) under eight air temperatures (T_a) ranging from 30°C to 52°C. Each experiment involved 1 hr of fixed and a second hour of progressively increasing water vapor pressure (P_w) with either air movement of 1 m/sec or still air. The equilibrium values of rectal temperature (T_{re}), mean skin temperature (T_{sk}), and heart rate (HR) reached in the first hour were forced upward in the second hour by the rising P_w . The critical P_w was defined by the T_{re} inflection point for each T_a . The loci of the critical P_w were used to delineate the thermal limits on the psychrometric chart and were used to derive the effective evaporative coefficient (K_e') applicable to the ambient capacity for evaporative cooling (E_{max}). The derived K_e' was $17.6 \pm 4.2 \text{ W/m}^2$ (mean \pm SD) for $v^{0.6}$ m/sec. Isotherms constructed on the basis of the obtained K_e' , T_{sk} , and sweating capacity were higher than the physiologically based P_w limits.

82. Kamon, E.; and Belding, H. S.:
Heart Rate and Rectal Temperature Relationships During Work in Hot Humid Environments.
J. Appl. Physiol., vol. 31, 1971, pp. 472-477.

Authors' Abstract

Nine young male subjects, acclimatized to heat, were exposed for 2 hr daily to work at about 25-35% of their maximal aerobic capacity in ambient temperatures of 36°-37°C and under the following treatment combinations: seminude or clothed, ambient water vapor pressure (P_a) at levels up to 40 mm Hg, wind velocities of 1.0, 2.5, or 3.3 m/sec, and level walking at 3.2, 4.5, or 5.6 km/hr. P_a either (1) was kept constant throughout the 2 hr but changed from day to day, or (2) was kept constant during the first hour, then was raised by 1 mm Hg each 10 min of the second hour. Continuous recording of rectal temperature (T_{re}) and heart rate (HR) showed that up to a certain critical P_a , depending on the other exposure conditions, the equilibrium level of each parameter is independent of P_a : T_{re} at about 37.9°C with small interindividual variation, HR at about 115 beats/min with large interindividual variation. Beyond the critical P_a both T_{re} and HR either equilibrate at higher levels or continue to rise to the end of the exposure time. Consecutive 10-min values of the experiments at and above the critical P_a were tested for linear correlation between T_{re} and HR. Individual regressions of T_{re} on HR averaged 0.029°C/beat, with an average standard error of estimate of $\pm 0.27^\circ\text{C}$; they agreed well with regression coefficients computed for some of the data in the literature on similar work levels but over a wider range of ambient air temperatures.

83. Kok, R.
Heat Tolerance of Bantu Undergoing Acclimatization.
So. Afr. Med. J., vol. 47, 1973, p. 960.

Author's Abstract

Most Bantu who are acclimatized to work in heat in the gold mining industry show a quick adaptation within 8 working days. A small percentage of men do not acclimatize successfully in this period. It is standard procedure that this group of men, known as heat-intolerants, are not allowed to work in heat, as the risk of developing heat stroke is very high among them.

A comparison between an acclimatized group of men and a group of heat-intolerant men was made to determine possible reasons for their inability to acclimatize. Previous studies on

heat-intolerance indicated that it is associated with age, body weight, and maximum oxygen intake. In this study these parameters were:

	Maximum oxygen intake, liters/min	Weight, kg	Age, yr
Heat-tolerant	3.10 ± 0.343	62.1 (54.3 - 73.2)	26.6 (17 - 41)
Heat-intolerant	2.42 ± 0.415	59.0 (48.4 - 76.0)	31.2 (18 - 53)
Significance of difference	1%	10%	10%

The main difference between the two groups was in their maximum oxygen intake. All heat-tolerant men have a maximum oxygen intake of more than 2.5 liters/min, whereas 63% of the heat-intolerant men had maximum oxygen intakes below this value.

Heat intolerance seems to be associated with the increased employment of foreign Bantu in the mining industry.

84. **Kotze, H. F.; van der Walt, W. H.; Rogers, G. G.; and Strydom, N. B.:**
Effects of Plasma Ascorbic Acid Levels on Heat Acclimatization in Man.
J. Appl. Physiol.: Respirat. Environ. Exercise Physiol., vol. 42, 1977, pp. 711-716.

Authors' Abstract

Thirteen male volunteers were heat acclimatized for 4 hr/day for 10 consecutive days. Three to four hours before each heat exposure, four of the subjects received an oral dose of 250 mg ascorbic acid, five received 500 mg ascorbic acid, and the remaining four a placebo. Rectal temperature, heart rate, and sweat rate were measured hourly during exposure. Venous blood samples were collected before each administration of drug or placebo. On days 1, 2, 3, 5, 8, and 10, blood samples were also collected just prior to heat exposure and after 2 and 4 hr of exposure. In the subjects receiving ascorbic acid, total circulating plasma ascorbic acid increased over the first 3 or 4 days to a plateau level some fourfold higher than in the subjects receiving the placebo. The plateau level was the same in the subjects receiving 250 mg and 500 mg ascorbic acid. The increased ascorbic acid concentration was shown to be associated with a reduction in total sweat output, independent of rectal temperature, and a reduction in rectal temperature, independent of total sweat output. The results indicate that ascorbic acid may be effective in reducing heat strain in unacclimatized individuals.

85. **Kuhlemeier, K. V.; Miller, J. M.; Dukes-Dobos, F. N.; and Jensen, R.:**
Determinants of the Prescriptive Zone of Industrial Workers.
J. Appl. Physiol.: Respirat. Environ. Exercise Physiol., vol. 43, 1977, pp. 347-351.

Authors' Abstract

The prescriptive zone is the range of climates in which man's body temperature is independent of climatic conditions. The environmental temperatures that define the upper limit of the prescriptive zone (ULPZ) at different work rates were determined in 46 clothed, healthy, male industrial workers; some of the men were job-acclimated to heat and some were not. They performed a total of 653 work bouts of low, medium, or high intensity in environments ranging from 11° to 35°C corrected effective temperature (CET) (8° - 37°C wet bulb globe temperature). Heart rates (HR) and rectal temperatures (T_{re}) were measured after 1 hr of work. The ULPZ was calculated from T_{re} data. HR's showed a similar pattern of response as T_{re} 's except that the inflection point corresponding to the ULPZ occurred at different environmental temperatures at most of the experiment conditions.

About one-third of the work bouts were performed in the summer months and the remainder in the winter. The ULPZ decreased with increasing work rates. At high, but not low, work rates, men who were exposed to heat in the performance of their jobs were more heat tolerant than men who were not heat acclimatized. Both groups were found to be more heat tolerant in the summer months than in the winter.

86. Laaser, U.:

Physiologische Reaktionen während eines fünfwochigen Daueraufenthaltes in einem Künstlichen Feuchtheissen Klima. (Physiologic Reactions During Five Weeks of Continuous Residence in an Artificial Humid and Hot Climate.)
Int. Z. Angew. Physiol., vol. 25, 1968, pp. 279-302.

Annotation

Purpose.

1. To determine the degree and point in time that acclimatization is achieved in case of protracted residence in a hot humid climate.
2. To determine what physiologic magnitudes permit the earliest assertion of the condition of acclimatization.
3. To establish in reference to sweat secretion the changes that go beyond the familiar simple increase [of sweat secretion].

Subjects. One male, age 25, height 189 cm, weight 80 kg.

Conditions.

<i>DBT/WBT/RH</i>	<i>Air</i>	<i>kcal/m² · hr)</i>	<i>Regimen</i>
36.5/31.3/69%	---	---	Work Program: 4x40 min, 15 min rest, Bicycle ergometer, 60 RPM and 8 m kp/sec Subject lived in hot environ for 35 days Subject submitted to work regimen 10 days prior to heat exposure and daily during remaining 35 days

Author's Summary.

In the course of a 5-week residence in a climatic room, total sweat secretion during work practically doubled. The initial differences between the individual hours became increasingly equalized (temporal redistribution). Furthermore there resulted a secretion redistribution in the direction of a displacement from trunk to extremities (local redistribution), which terminated at about the end of the third week. This displacement was earlier and relatively easier to notice for the arm than for the leg.

As differences between individual hours decreased, work temperatures dropped rather rapidly and uniformly to a fairly constant end level by day 11.

The behavior of the blood circulation matches that of the temperatures. Pulse rate during work, like rectal temperature during work, drops during the first 10 days to a constant end level, which is only slightly higher than the values obtained during cold training. The behavior of the pulse rate during rest is basically like that of the corresponding temperatures.

Outside of the first days, urine output was adequate and even. Na in the urine decreases until week 3 of the experiment, probably due to a salt deficit, but then returns to initial values.

Over the experimental period the Na and K concentrations in the sweat decline. However from hour 1 to hour 4 the Na concentration increases, whereas the K concentration declines. Total salt elimination decreases in the course of the acclimatization process.

According to our test results the conclusive phenomena of redistribution occur within the first 3 weeks. Only a few functions undergo change later as well:

1. The mean skin temperature gradient at the end of hour 4 rose in the direction of the core temperature gradient.

2. Sweat secretion increased in the fourth hour to approximate that in hours 1 to 3.

These relatively inconsequential changes in an otherwise uniform reaction pattern indicate, just as does the behavior of the sweat response, that after 3 or even 5 weeks, the acclimatization process is not over, or at least not completely so.

The tempo of the acclimatization process appears to be a function of the degree of total heat and work loading.

87. Lahiri S.; Weitz, C. A.; Milledge, J. S.; and Fishman, M. C.:
Effects of Hypoxia, Heat, and Humidity on Physical Performance.
J. Appl. Physiol., vol. 40, 1976, pp. 206-210.

Authors' Abstract

The effects of hot, humid environment were compared with the effects of high altitude on the physical performance capacity of Nepalese residents by measuring oxygen uptakes and heart rates at various work rates. The following groups of men were selected: 66 residents of a hot and humid environment in the Terai at sea level; 24 residents and 16 sojourners at 3,800 m. The maximal oxygen uptake of the sea-level residents was, on the average, 2.55 l/min, at which a maximal heart rate of about 200 beats/min was reached. The sojourners at 3,800 m showed a higher maximal oxygen uptake (2.94 l/min) at their maximal heart rate of about 175 beats/min. The residents of 3,800 m achieved a similar oxygen uptake as the sojourners, but did not show a similar maximal heart rate limitation, suggesting that they were capable of achieving a higher maximal oxygen uptake. This study shows that hot, humid environment at sea level is as much incapacitating as is hypoxia at high altitude.

88. Leibowitz, H. W.; Abernethy, C. N.; Buskirk, E. R.; Bar-Or, O.; and Hennessy, R. T.:
The Effect of Heat Stress on Reaction Time to Centrally and Peripherally Presented Stimuli.
Hum. Factors, vol. 14, 1972, pp. 155-160.

Authors' Abstract

The effect of heat stress on reaction time to centrally and to peripherally presented stimuli was determined for lean and obese subjects whose work levels on a treadmill in a heat chamber produced either a 2.5% or 5% loss of body weight in 6 hr. Peripheral reaction time improved with practice, but central reaction time was not affected. Obesity, eccentricity of the peripheral stimulus, and the level of dehydration did not have significant effects on reaction time. It was concluded that for short periods of time, the effects of heat stress can be overcome for highly motivated and experienced subjects.

89. Lind, A. R.; Humphreys, P. W.; Collins, K. J.; Foster, K.; and K. F. Sweetland.
Influence of Age and Daily Duration of Exposure on Responses of Men to Work in Heat.
J. Appl. Physiol., vol. 28, 1970, pp. 50-56.

Authors' Abstract

Six young men (23-31 yr) and six older men (39-53 yr) were exposed to five different climates, three of which lay in the prescriptive zone while the other two were hotter. Exposures were for 8 hr and the total energy cost was nearly 2,000 kcal. In the three prescriptive climates, differences in the responses of the two age groups were small and consistent; rectal temperature was similar for each age group in all three climates. In the two hotter climates, rectal temperature increased above prescriptive levels in both age groups, but more so for older men. The duration of exposure hardly affected the responses of either group in the prescriptive climates, but in the hotter climates rectal temperature increased with time; again the older men exhibited a selectively greater strain. Since there was little or no difference in the strain in the two groups of men in the three coolest climates, the results lend confidence to the use of the prescriptive zone to set thermal environmental limits for everyday work.

90. Maher, J. T.; Bass, D. E.; Heistad, D. D.; Angelakos, E. T.; and Hartley, L. H.:
Effect of Posture on Heat Acclimatization in Man.
J. Appl. Physiol., vol. 33, 1972, pp. 8-13.

Authors' Abstract

Cardiovascular, thermoregulatory, and sympathoadrenal responses of two matched groups of four men each were compared during daily 90-min periods of upright and supine bicycle exercise at 49° dry-bulb and 27°C wet-bulb temperatures. The groups underwent 8 consecutive days of exercise in the heat at the same work load and level of oxygen consumption, preceded and immediately followed by a uniformity trial in which they walked on a treadmill at 5.6 km/hr. The group that exercised while supine performed with lower mean rectal temperatures ($P < 0.005$) and lower heart rates ($P < 0.05$) than the group that exercised while upright. Sweat rates were similar for the two groups. Both groups were successfully acclimatized to heat as evidenced by significantly lower rectal temperatures and heart rates, and higher sweat rates after 8 days of exercise in the heat. The responses of the two groups to treadmill exercise were similar, indicating that both groups were acclimatized to a similar degree. Norepinephrine excretion during exercise tended to be greater while subjects were upright and tended to decrease during acclimatization. It appears that the reduced gravitational stress of the recumbent position permits attainment of a level of acclimatization to work in the heat similar to that achieved in the upright posture with the benefit of less physiologic strain during induction of acclimatization.

91. Malhotra, M. S.; Sridharan, K.; and Venkataswamy, Y.:
Potassium Losses in Sweat under Heat Stress.
Aviat. Space Environ. Med., vol. 47, 1976, pp. 503-504.

Authors' Abstract

Six healthy, heat-acclimatized subjects were exposed to different hot and humid environments in a climatic chamber. Sodium, potassium, and chloride concentrations in their sweat, urine, and blood were determined. The concentration of potassium in sweat was found to be considerably higher than that in the plasma; the concentrations of sodium and chloride were very much lower. The concentration of potassium in urine was also 8 times higher than that in the plasma, compared with 0.5 to 1.5 times higher for sodium and chloride. The total daily computed losses of potassium in sweat and urine, of a person working in heat in the tropics, can be about 116 meq as against a dietary

intake of 97 meq/day, thereby resulting in negative potassium balance. The potassium depletion in sweat, even in acclimatized Indians, is thus heavy and is likely to play an important role in the causation of heat-illness.

92. **Marcus, P.:**

A Further Study Concerning Heat Acclimatization Using the Insulated Vapour Barrier Suit Technique.

R. A. F. Inst. Aviat. Med. I.A.M. Report No. 512, 1971.

Author's Summary

1. A study has been carried out using one subject in which acclimatization to heat has been induced by 15 daily elevations of deep-body temperature to 38.5°C.
2. Elevation of body temperature was achieved by performing various forms of exercise for 2 hr daily while wearing a vapor-barrier suit with added external insulating clothing layers that were changed according to the climatic conditions in a wide range of localities both in and out of doors.
3. Following the attainment of a steady acclimatization state, further exercise periods were undertaken by the subject to investigate maintenance of heat acclimatization achieved by this method.
4. It was found that one exposure every 4 to 7 days sufficed to maintain acclimatization for 2.5 months.

93. **Marcus, P.:**

Heat Acclimatization by Exercise-Induced Elevation of Body Temperature.

*J. Appl. Physiol., vol. 33, 1972, pp. 283-288.**

Author's Abstract

An experiment was undertaken in which eight male subjects performed 17 daily (excluding weekends) exercise periods in a room conditioned at 10°C dry bulb. All of the subjects wore vapor barrier suits, half with much added external insulation and half with little. They stepped on foot stools so as to raise their deep-body temperatures to 38.3°C and maintained the temperatures at that level by further exercise for 1 hr daily. Those subjects wearing much insulation performed considerably less exercise than those wearing less, but they had higher skin temperatures. Tests carried out before and after the runs showed better levels of physical fitness, higher sweat rates, and lower body temperatures and heart rates in the heat following the treatment. The responses of the two groups did not significantly differ. It is concluded that heat acclimatization may be induced by elevation of body and skin temperatures by exercise in insulated vapor barrier suits. Under the circumstances of this experiment skin temperature and exercise levels did not affect the response.

94. **Marcus, P.; and Field, D.:**

A New Portable Temperature-Sensing Device.

J. Appl. Physiol., vol. 34, 1973, pp. 374-376.

Authors' Abstract

A sturdy, lightweight, man-mounted thermometric device is described. The apparatus is intended for use in a practical heat acclimatization technique involving exercise in insulated vapor barrier clothing and allows a subject to control his own body temperature at various elevated levels. A red and green light system with a calibrated dial provides an accurate indication of temperature when operated by untrained personnel. Possible alternative uses are considered.

*Same as: Marcus, P.: Heat Acclimatization by Exercise-Induced Elevation of Body Temperature in a Cool Environment. I.A.M. Report, No. 509. Hampshire: R.A.F. Institute of Aviation Medicine, 1971, p. 33.

95. Maron, M. B.; Wagner, J. A.; and Horvath, S. M.:
Thermoregulatory Responses during Competitive Marathon Running.
J. Appl. Physiol., Respirat. Environ. Exercise Physiol., vol. 42, 1977, pp. 909-914.

Authors' Abstract

To assess thermoregulatory responses occurring under actual marathon racing conditions, rectal (T_{re}) and five skin temperatures were measured in two runners approximately 9 min during a competitive marathon run under cool conditions. Race times and total water losses were: runner 1 = 162.7 min, 3.02 kg; runner 2 = 164.6 min, 2.43 kg. Mean skin temperature was similar throughout the race in the two runners, although they exhibited a marked disparity in temperature at individual skin sites. T_{re} plateaued after 35-45 min (runner 1 = 40.0-40.1, runner 2 = 38.9-39.2°C). While runner 2 maintained a relatively constant level for the remainder of the race, runner 1 exhibited a secondary increase in T_{re} . Between 113 and 119 min there was a precipitous rise in T_{re} from 40.9° to 41.9°C. Partitional calorimetric calculations suggested that a decrease in sweating was responsible for this increment. However, runner 1's ability to maintain his high T_{re} and running pace for the remaining 44 min of the race and still exhibit no signs of heat illness indicated thermoregulation was intact.

96. Martineud, J. P.; Raynaud, J.; Duhaize, P.; and Vieillefond, H.:
Modifications du débit sanguin de la main et de la réactivité vasculaire avec l'acclimatation à la chaleur. (Modifications of the Blood Flow in the Hand in the Reactive Vasculature with Heat Acclimatization.)
J. Physiol. (Paris), vol. 72, 1976, pp. 233-247.

Authors' Abstract

Three groups of subjects, Europeans without any heat acclimation (called EE), Europeans after 3 weeks of acclimatization in India (EI), and Indians in their natural environment (II) were studied during exposure to an ambient temperature of 33°C. Hand blood flow (\dot{Q}), rectal temperature (T_{re}), and mean cutaneous temperature (\bar{T}_{sk}) were simultaneously recorded at rest and during 2 periods of muscular exercise (0.4 and 0.7 $\dot{V}O_2$ max) of 35 min duration.

The results showed (1) at rest, \dot{Q} was very high in EE, quite low in both EI and II; (2) at the onset of exercise, a hand vasoconstriction was observed in all cases; (3) during exercise, there was a progressive increase of \dot{Q} until 200% maximum above rest values; (4) at the end of exercise, \dot{Q} was proportional to the intensity of the exercise for each group and inversely proportional to the duration of heat exposure, the highest \dot{Q} being observed in EE, the lowest in II, and an intermediate value for EI close to the latter).

These differences in hand blood flow could not be explained by differences in deep-body or superficial temperatures between subjects. Thus, during chronic heat exposure, there is, especially for an exercising man, a progressive modification of heat transport in the body: that is, a reduction of skin perfusion and a greater $T_{re}-\bar{T}_{sk}$ difference; both T_{re} and \bar{T}_{sk} are adaptative responses. The value of hand blood flow as an estimation of whole superficial circulation is discussed.

97. McArdle, W. D.; Magel, J. R.; Lesmes, G. R.; and Pechar, G. S.:
Metabolic and Cardiovascular Adjustment to Work in Air and Water at 18, 25, and 33°C.
J. Appl. Physiol., vol. 40, 1976, pp. 85-90.

Authors' Abstract

By use of successive increments of discontinuous work with an arm-leg cycle ergometer the $\dot{V}O_2$, \dot{Q} , SV, and HR were studied in six male subjects at rest and during exercise in air and in water at 18°, 25°, and 33°C. The \dot{Q} values obtained by CO_2 rebreathing were reproducible. $\dot{V}O_2$ was linearly

related to work with the plots for air and 33°C water being similar. However, during work in 25° and 18°C water, the $\dot{V}O_2$ averaged 9.0% (150 ml) and 25.3% (400 ml) higher, respectively, than values observed in 33°C water, with the largest differences observed in leaner subjects. The plot of HR· $\dot{V}O_2$ was linear and almost identical during work in air and 33°C water, but shifted significantly to the right in cooler water. $\dot{V}O_2$ averaged 250–700 ml higher in cold water compared with air and 33°C water at a given mean heart rate. The Q vs $\dot{V}O_2$ line was similar during work in air and in water with no effect of water or temperature. At similar levels of $\dot{V}O_2$, SV was significantly larger ($P<0.05$) in 25° and 18°C water than in air or 33°C water. Consequently, the reduction in heart rate during work in cold water was entirely compensated for by a proportionate increase in the SV of the heart. Q was therefore maintained at similar levels of energy expenditure in air and in 18°, 25°, and 30°C water.

98. McCaffrey, T. V.; Geis, G. S.; Chung, J. M.; and Wurster, R. D.:
Effect of Isolated Head Heating and Cooling on Sweating in Man.
Aviat. Space Environ. Med., vol. 46, 1975, pp. 1353–1357.

Authors' Abstract

A double climate chamber, which permitted the independent regulation of temperature in each chamber, was used to produce isolated head heating and cooling in three subjects. Deep-body temperature was recorded from the tympanic membrane, oral cavity, esophagus, and rectum. Skin temperature was measured on nine body regions and a weighted mean skin temperature was calculated. Sweating rate was measured by resistance hygrometry from six regions. When head skin temperature was increased, deep-body temperature measured at the tympanic membrane and oral cavity increased more than esophageal temperature; rectal temperature remained essentially unchanged. Sweating rate increased when head skin temperature increased and again, somewhat later, as the tympanic membrane and oral temperatures began to rise. When head-skin temperature was decreased, tympanic membrane and oral temperatures decreased, and sweating again followed the changes in skin temperature as well as the changes in tympanic membrane and oral temperatures. Since it has been shown that head-skin temperature is particularly important in determining thermal comfort and sweating rate when compared to other body regions, it is suggested that this particular sensitivity is in part due to a thermal counter-current exchange between venous blood draining the head and arterial blood ascending to intracranial thermoreceptors. Such an exchange would correspond to similar mechanisms present in other species.

99. McCance, R. A.; Abu Rabiyah, Y.; Beer, G.; Edholm, O.G.; Even-Paz, Z.; Luff, R.; and Samueloff, S.:
Have the Bedouin a Special 'Desert' Physiology?
Proc. Roy. Soc. London, Series B, vol. 185, 1974, pp. 263–271.

Authors' Abstract

Ten male Bedouin from the Negev have been compared with the same (or for one test a much larger) number of Jewish male students of a similar age.

Their heights, weights and serum chemistry were similar although the Bedouin were somewhat thinner. The response of the sweat glands to pilocarpine was smaller in the Bedouin than in the controls. Their forearm bloodflows at rest were greater. Their production of sweat in response to a rise of deep-body temperature was the same and so was their working capacity and the concentrating power of their kidneys.

Physiologically speaking, therefore, Bedouin did not appear to be better adapted to life in the desert than other human ethnic groups.

100. McGavock, H.; and Turk, J.:
The Effects of Acclimatization to Heat on Evaporative Cooling From High Body Temperatures in Man.
J. Physiol. (London), vol. 205, 1969, pp. 12P-13P.

Authors' Abstract

The adaptations of acclimatization to heat in man, which result in an increased cooling capacity of the body, include an increased sweat rate and skin blood flow, in response to a standardized thermal stimulus. The present preliminary experiments were designed to study the increase in cooling capacity by following the return of body temperatures from high levels toward normal in a standard climate, before and after acclimatization.

The subjects were three healthy young soldiers. A standard-climate evaporative cooling (SCEC) test was done on three consecutive days, before and after acclimatization. Acclimatization was induced by 11 daily 60-min periods of controlled hyperthermia at 38.4°C aural temperature. Each controlled hyperthermia period was also a thermoregulatory function (TF) test (Fox, Crockford & Löfstedt, 1968). For all tests, skin, sublingual and external auditory meatal temperatures were measured, using thermistor thermometers accurate to $\pm 0.05^\circ\text{C}$. The subject was clad to the neck in an airtight plastic suit, from which sweat was collected by suction. The head was thermally insulated. In the SCEC test he was heated by forced convection of air at 54°C, in a one-man climatic box, to an aural temperature of 38.9°C and maintained within 0.1°C of that target for 5 min. Following rapid divesting of the plastic suit, he was exposed to an airstream of constant velocity at 38.0°C dry bulb ($\pm 0.2^\circ\text{C}$) and 4.5°C dew point ($\pm 0.5^\circ\text{C}$). Under these conditions heat was lost largely through evaporation with forced convection. Deep-body temperatures during cooling were recorded at 30 sec intervals.

The TF tests showed a marked increase in heat acclimatization during the 11 days of heat treatment, so that the 60-min sweat loss was increased 92.8% (mean). Reproducibility of the SCEC deep-body temperature cooling curves was satisfactory. Following acclimatization, the asymptotic value of the curves, approached after 35 min of cooling, fell 0.43°C (mean), which supports previous evidence for lowered set-point of body temperature regulation following heat acclimatization. Analysis shows that the SCEC curves approximate closely the cooling law of Ferguson and Miller (1933), given by: $d\theta/dt = 4\alpha\theta^{5/4}$; where t is time, θ is excess temperature above the asymptotic value, and α is a constant. The slope of the almost linear first segment of the curve gives the initial rate of deep-body cooling. Following acclimatization, the mean slope for the three subjects was increased 45.5% which is less than would be predicted from the 92.8% increase in sweat loss, suggesting that under these conditions heat transport by the cardiovascular system is a limiting factor in the rate of body cooling.

101. Meyerstein, N.; Shvartz, E.; Benor, D.; and Saar, E.:
Effect of Controlled Heat Acclimation on the Human Red Blood Cell.
Aerospace Med., vol. 45, 1974, pp. 727-729.

Authors' Abstract

The effect of controlled heat acclimation on the human red blood cell (RBC) was determined in six young men who performed mild work for 6 days in dry heat at 50°C. The experiments were carried out in winter to obviate the effects of seasonal acclimatization. Heat acclimation did not affect the glycolytic rate, ATP content, and osmotic fragility of the red blood cells. No changes were found either in age distribution, mean corpuscular hemoglobin concentration, or RBC concentration in the blood. Thus, it may be concluded that heat acclimation has no ill effect on the human red blood cell.

102. Miller, G. J.; and de V. Martin, H.:

Effect of Ambient Temperatures Between 21°C and 35°C on the Responses to Progressive Submaximal Exercise in Partially Acclimated Man.
Ergonomics, vol. 18, 1975, pp. 539-546.

Authors' Abstract

The effects of variation in dry-bulb temperature between 21°C and 35°C on the physiological responses to a 12-min progressive submaximal exercise test have been examined in four healthy men partially acclimated to heat. On average, cardiac frequency and minute ventilation at standard oxygen uptake increased by 1·4% ($r=0\cdot85$; $p<0\cdot001$) and 0·4% ($r=0\cdot46$; $p<0\cdot001$), respectively, for each degree rise in dry-bulb temperature. The increase in exercise cardiac frequency with each degree rise in mean skin temperature averaged 5·1%. A regression relationship is presented which permits adjustment of the cardiac frequency at standard oxygen uptake to either a standard dry-bulb temperature or mean skin temperature. Its use and limitations are illustrated using data collected during studies that formed part of the U.K. contribution to the International Biological Programme.

103. Mitchell, D.; Senay, L. C.; Wyndham, C. H.; van Rensburg, A. J.; Rogers, G. G.; and Strydom, N. B.:

Acclimatization in a Hot, Humid Environment: Energy Exchange, Body Temperature, and Sweating.

J. Appl. Physiol., vol. 40, 1976, pp. 768-778.

Authors' Abstract

Four trained young men, worked for 4 hr/day at 40-50% of their maximum aerobic capacity for 3 days at 25°C dry bulb, 18°C wet bulb, and then for 10 consecutive days at 45°C dry bulb, 32°C wet bulb. Their thermal status was assessed using direct calorimetry. As a group, the men showed classical acclimatization responses, but there were marked individual differences. The calorimetric analysis revealed that reductions in strain were associated with minor changes in heat balance confined to the first and last hours of exposure. Events occurring within the first 4 days appeared to have little effect on body temperatures. Significant decreases in body temperature took place only when sweat and evaporation rate increased. A 10% increase in evaporation rate was accompanied by a 30% increase in sweat rate and a 200% increase in unevaporated sweat; thus, there is a wasteful overproduction of sweat. By the tenth day skin temperature was confined to the level necessary to evaporate sufficient sweat to achieve thermal balance with a fully wet body surface. The efficiency of heat transport within the body did not change with acclimatization.

104. Morimoto, T.; Slabochova, Z.; Naman, R.; and Sargent, F., II:

Sex Differences in Physiological Reactions to Thermal Stress.

J. Appl. Physiol., vol. 22, 1967, pp. 526-532.

Authors' Abstract

Thirteen young men, aged 17-32, and 13 young women, aged 18-23, were exposed five times for 2 hr to increasing heat with either low or high humidity. Measurements were made of the total body and forearm sweat rate, sweat chloride concentration, rectal and skin temperature, blood pressure, pulse rate, and respiratory metabolism. A remarkable sex difference was observed in the sweat rates; they were significantly higher in the men, especially under higher heat either dry or moist. There was a definite depression of sweating by high humidity in both sexes. As heat stress increased, systolic blood pressure rose slightly in the women, diastolic decreased much more in the men. Total heat production, lower in the women, increased relatively more among them under the influence of heat and treadmill walking. In the other parameters, no influence of the humidity or sex was found. Large individual variations of sweat chloride concentration were observed. No signs of acclimation

developed. It is concluded that even at equivalent levels of P_4SR the effects of dry and moist heat on sweating differ.

105. Nadel, E. R.; Horvath, S. M.; Dawson, C. A.; and Tucker A.:
Sensitivity to Central and Peripheral Thermal Stimulation in Man.
J. Appl. Physiol., vol. 29, 1970, pp. 603-609.

Authors' Abstract

A thermoregulatory response in man was stimulated by inducing a constant central (tympanic) temperature increase or decrease in each of seven ambient environments ranging from 10° to 44°C. The characteristics and magnitude of this thermoregulatory response were found to be dependent on the thermal information at the skin surface. At average skin temperatures below 32°-34°C, increased heat production occurred in response to the central temperature decrease, the amount of increase in heat production being directly dependent on skin temperature. In the middle ranges of skin temperature, reductions in peripheral circulation (increased body insulation) was the physiological mechanism toward repayment of the heat debt, while at average skin temperatures greater than 34°-35°C, a reduction in evaporative heat loss occurred. At any given skin temperature, the thermoregulatory responses were proportional to the reduction in central temperature. Alterations in each physiological response (heat production, peripheral circulation, sweating rate) were attributed to deep-body and mean skin temperature interrelations along mean skin temperature response curves. This hypothesis was able to describe the physiological regulation without the necessity of postulating a shift in hypothalamic set point. The following description of the metabolic response supported this concept: $\Delta M = 36 \text{ kcal/hr} (36.5^\circ\text{C} - T_{hc}) (32.2^\circ\text{C} - \bar{T}_s) + 7 \text{ kcal/hr} (32.2^\circ\text{C} - \bar{T}_s)$.

106. Nadel, E. R.; Pandolf, K. B.; Roberts, M. F.; and Stolwijk, J. A. J.:
Mechanisms of Thermal Acclimation to Exercise and Heat.
J. Appl. Physiol., vol. 37, 1974, pp. 515-520.

Authors' Abstract

Six relatively unfit (average $\dot{V}O_2$ max = 38.1 ml/min/kg) males underwent 10 consecutive days of physical training on a bicycle ergometer for 1 hr/day at between 70 and 80% of their individual $\dot{V}O_2$ maxima. Following physical training, these six subjects underwent 10 consecutive days of heat acclimation by exercising 1 hr/day at 50% $\dot{V}O_2$ max, three subjects in a 45°C, dry ambient and three subjects in a 36°C, humid ambient. Training provided a mean increase in $\dot{V}O_2$ max of 6.6 ml/min/kg. Heat acclimation was accompanied by significant reductions in heart rate and internal temperature over the 10 days. From the unfit to relatively fit condition, an enhanced sweating responsiveness was achieved by an increase of 67% in the relation of local sweating rate to internal temperature, with no change in the zero point of central sweating drive. From the fit to the heat-acclimated condition, increased sweating capabilities were arrived at by a reduction in the point of zero central drive, with no change in the relationship of local sweating rate to internal temperature. Thus, a potentiation in the heat dissipation response is achieved via peripheral mechanisms during physical training and via central mechanisms during heat acclimation.

107. Nadel, E. R.; Roberts, M. F.; Wenger, C. B.; and Stolwijk, J. A. J.:
Sweating and Skin Blood Flow Control During Progressive Acclimation.
Israel J. Med. Sci., vol. 12, 1976, pp. 812-814.

Annotation

Purpose. To determine whether dissipation of a given thermal load at relatively lower thermal drives is accompanied by reductions in peripheral demands.

Subjects. Five unfit subjects.

Conditions.

<i>DBT/WBT/RH</i>	<i>Air</i>	<i>kcal/(m²·hr)</i>	<i>Regimen</i>
1. 22° / - / -	---	---	1. Pretest, $\dot{V}O_2$ max
2. 22° / - / -	---	---	2. 1 hr daily bicycle ergometer exercise, four 15-min bouts separated by 5-min rest periods, at 70-80% $\dot{V}O_2$ max for 10 days
3. 36° / - / 35 Torr			3. Same as condition 2, except at 50% $\dot{V}O_2$ max; all subjects underwent condition 1 followed by condition 2 and then 3.

Results.

1. Ten days physical training increased $\dot{V}O_2$ max in all subjects by 15%.
2. Heart rates and internal temperatures were further reduced during the 10 days of heat-and exercise-acclimation.
3. In three subjects progressive acclimation was accompanied by increased forearm blood flow as well as a reduced (-0.3°C) threshold for the onset of the increase.
4. In all subjects, progressive acclimation was accompanied by lowered thresholds of sweat onset relative to internal temperature (-0.3°C).
5. Blood flow rates (average response) did not change significantly during progressive acclimation.
6. Physical training induced a 60% increase in the scope of the sweat rate and internal temperature relationship. However, no change in the scope occurred after the exercise-acclimation condition.

Conclusions.

1. Physical training and heat acclimation both enhance the ability to sweat at a given central thermoregulatory drive.
2. The enhancement of sweating is by peripheral mechanisms during physical training and by central mechanisms during heat acclimation.

108. Nunneley, S. A.:

Physiological Responses of Women to Thermal Stress: A Review.
Med. Sci. Sports, vol. 10, 1978, pp. 250-255.

Author's Abstract

The recent increase in women's participation in physically challenging activities prompted this review of female responses to heat and cold (68 references). Relevant sex differences include hormone levels, anthropometric factors, and body composition. Many studies show that women are less heat tolerant than men, particularly when physical work is required. Much of the difference is related to women's relatively low level of physical fitness and lack of heat acclimatization, which are in turn a result of their traditionally sedentary lifestyle. When work load is adjusted relative to individual capacity, females respond to heat stress much as males do. Acclimatization mechanisms are the same. Women generally have lower sweat rates, an appropriate adjustment to lesser cooling

needs. The menstrual cycle has no meaningful effect on heat tolerance. Cold response reflects individual subcutaneous fat thickness, and women have an advantage there, but in extreme cold exposure they may be handicapped by their small muscle mass. Sex *per se* is but a small factor in determining human thermal responses, individual body size, physical fitness, and state of acclimatization play far more important roles.

109. Nunneley, S. A.; and Myhre, L. G.:

Physiological Effects of Solar Heat Load in a Fighter Cockpit.
Aviat. Space Environ. Med., vol. 47, 1976, pp. 969-973.

Authors' Abstract

The use of bubble canopies to improve vision in fighter aircraft exposes the cockpit to a high radiant heat load. Incoming sunlight increases the heat stress on crewmembers, both by raising air temperature and by directly heating exposed skin and clothing. An F-15 aircraft at Edward's AFB was modified to permit cockpit ventilation by external ground carts. Eight volunteers from the Test Pilot School were studied during 1-hr periods in the closed cockpit, in sun and in shade. Mean cockpit air temperatures were 35.2°C in shade and 51.9°C in sun with PH₂O < 10 Torr. The corresponding WBGT's were 22.6° and 36.4°C. Sunlight added significantly to overall heat stress, as indicated by a rising heart rate and evaporative weight loss of 284 g/(m²·hr) (shade value was 109 g/(m²·hr)). Mean skin temperatures were 34.3°C in shade and 35.8°C in sun. Particularly high skin temperatures were observed on the chest, the forehead and the top of the head under the helmet. The legs remained cool due to the flow of conditioned air, and this may explain why rectal temperature showed no meaningful change. Heat stress, which alone poses no physiological hazard, may cause crew performance decrements as well as diminishing acceleration tolerance. Possible means of eliminating or ameliorating these effects are discussed.

110. Ohara, K.; Okuda, N.; and Takaba, S.:

Thermoregulatory Responses to Heat and Exercise in Japanese and Caucasians.
Int. J. Biometeor., vol. 19, 1975, pp. 99-107.*

Authors' Abstract

Responses to heat and exercise were studied in nine male Japanese subjects who walked on a treadmill at a speed of 4.4-4.8 km/hr at 0% grade for 2 hr in a climatic chamber in July 1973, in Nagoya Japan. The results were compared with those obtained in a similar study made in July 1966 in Cincinnati, Ohio. The following results were obtained: (1) Japanese showed a 1.8 times higher rate of sweating than Caucasians. Total sweat from the whole body during 2 hr walk was also higher in Japanese. (2) Japanese exhibited lower chloride concentration in local sweat than Caucasians in spite of their higher dietary salt intake, higher serum chloride concentration, and higher rate of sweating. While in Caucasians the sweat chloride concentration showed a tendency to continue to rise during the later period of the walk in spite of decreasing sweat rate after sweat suppression occurred, in Japanese it tended to fall in parallel with the sweat rate. No difference was observed in the length of the latent time of sweat suppression. (3) There were no differences in rectal temperature or heart rate, both at the period of equilibrium rectal temperature and at the end of the walk. (4) Mean skin temperature during the walk was significantly higher in Japanese than in Caucasians. It was concluded that the Japanese group was better heat acclimatized than Caucasians, though the two groups were considered to have been naturally heat exposed by season to the same extent.

*Same as: Ohara, K.; Okuda, N.; and Takaba, S.: Thermoregulatory Responses to Heat and Exercise in Japanese and Caucasians. Comparative Studies on Human Adaptability of Japanese, Caucasians, and Japanese Americans; S. M. Horvath, S. Kondo, H. Matsui, and H. Yoshimura, eds., University of Tokyo Press, Tokyo, 1975, pp. 145-154.

111. Pandolf, K. B.; Burse, R. L.; and Goldman, R. F.:
Role of Physical Fitness in Heat Acclimatisation, Decay and Reinduction.
Ergonomics, vol. 20, 1977, pp. 399-408.

Authors' Abstract

Loss of heat acclimatization was investigated, in winter after decay periods of 3, 6, 12, and 18 days, by evaluation of the residual retention and the time necessary for reinduction. Twenty-four fit soldiers (mean $\dot{V}O_2$ max = 49.5 ml/kg/min) were concurrently heat acclimatized for 9 days, walking 1.34 m/sec for 110 min each day at 49°C, 20% RH, 1.4 m/sec wind. Physiological measurements included heart rate (HR), rectal temperature (T_{re}), mean skin temperature (\bar{T}_s), and sweat rate. Final mean T_{re} at 110 min decreased from 39.1°C (day 1) to 38.3°C (day 9), and final mean HR from 160 beats/min to 124 beats/min ($p < .01$). An individual's $\dot{V}O_2$ max was significantly related ($r = -0.68$) to the number of days for his T_{re} to plateau during acclimatization. For the decay and reacclimatization, four groups were formed (six subjects each), homogeneous in $\dot{V}O_2$ max; the mean $\dot{V}O_2$ max for each group was 49.5 ± 1 ml/kg/min. Initial percent loss of acclimatization was small ($p > 0.05$) for all groups (3, 6, 12, and 18 days) ranging from group mean losses in T_{re} of 0-18% and in HR of 2-29%; using T_{re} and HR criteria, all groups reacclimatized within 2 days. Their physical fitness is hypothesized as the prime factor in the small decay and rapid reacclimatization of these subjects even after 18 days.

112. Pandolf, K. B.; Gonzalez, R. R.; and Gagge, A. P.:
Physiological Strain During Light Exercise in Hot-Humid Environments.
Aerospace Med., vol. 45, 1974, pp. 359-365.

Authors' Abstract

Physiological strain, measured by skin (\bar{T}_{sk}) and esophageal (T_{es}) temperatures, heart rate (HR), and skin evaporative heat loss (E_{sk}), forearm sweat rate, and skin conductance, was compared at 25°, 32° and 40°C ambient. Six unacclimated males did bicycle ergometer exercise for 30-40 min at 25% $\dot{V}O_2$ max, during which humidity (P_a) was constant (10 Torr) or increased steadily toward saturation. For low P_a , HR rose 1 beat/min per °C elevation above 25°C. For increasing P_a , heart rate rose 2-4 beats/min for each °C above 25°C ambient without thermal equilibrium. With rising humidity, T_{es} and \bar{T}_{sk} rose at a greater rate than for low humidity; the fraction of secretory sweat, effective as evaporative cooling, was limited by excessive wetting on exposed skin surface. Local sweating was a direct index of metabolic heat load, and total body sweating was an index of external heat load; together they serve as more realistic indices of heat strain than prescriptive limits set by HR and T_{es} alone.

113. Pandolf, K. B.; and Kamon, E.:
Respiratory Responses to Intermittent and Prolonged Exercise in a Hot-Dry Environment.
Life Sci., vol. 14, 1974, pp. 187-198.

Authors' Abstract

Ventilatory gas exchange ratio (R), $\dot{V}O_2$, ventilation (\dot{V}_E), respiration rate (RR), rectal temperature (T_{re}), and heart rate (HR) were determined for four acclimatized subjects during intermittent and prolonged exercise on a treadmill at 24° and 45°C (dry) as follows: (1) eight cycles (10 min exercise and 5 min rest), and (2) prolonged exercise lasting for 90 min. Although during intermittent and prolonged exercise, $\dot{V}O_2$ and \dot{V}_E did not differ in the heat, RR, T_{re} , HR, and the respiratory dead space were higher in the hot ambient environment. After steady-state attainment, exercise R was higher in the initial than in the last cycles with higher values in neutral than in the

hot ambient condition. It was concluded that heat was more effective than time in lowering the R, probably with a greater dependence on fat oxidation in the latter exercise cycles, which seemed to be more pronounced in the heat.

114. Paolone, A. M.; Wells, C. L.; and Kelly, G. T.:
Sexual Variations in Thermoregulation During Heat Stress.
Aviat. Space Environ. Med., vol. 49, 1978, pp. 715-719.

Authors' Abstract

Four male and three female physically fit, but untrained subjects performed a treadmill walking task in neutral (25°C), warm (32°C), and hot (40°C) environments. The treadmill grade for each subject was based on 50% $\dot{V}\text{O}_{\text{max}}$ as determined in a neutral environment. Environmental exposures were 2 hr in duration divided into 40 min of rest, work and recovery. No distinct sexual differences in rectal and skin temperature responses were observed in the three environments. The male subjects had higher heart rates and greater evaporative weight losses during exercise in all environments. The female subjects experienced less severe increases in metabolic requirements during work in the warm and hot environments than the male subjects. The greater percentage of increase in heart rates relative to changes in the metabolic cost of work in the females suggested a greater cardiovascular component of thermal regulation in the female than in the male subjects. The results of this study suggest that physically fit females are capable of working in the heat about as well as males when work load is relative to individual maximal aerobic capacity.

115. Peter, J.:
Voluntary Body Water and Salt Deficits as a Cause of Differences Between Men in Their Tolerance to Heat.
Pflügers Arch., vol. 322, 1971, pp. 22-34.

Annotation

Purpose. To study the individual variation in heat tolerance during salt and water deficits.

Subjects. Forty-nine unacclimatized Bantu mine workers.

Conditions.

DBT/WBT/RH	Air	kcal/(m ² ·hr)	Regimen
34°C/32°C/87%	---	---	All subjects underwent one exposure only for 4 hr while exercising at 207 kgm/min Group 1 (half the subjects) replaced sweat losses by drinking water during exercise Group 2 was not allowed fluid replacement

Results.

1. There was no significant difference in the fourth hour rectal temperature between the groups (1 = 38.9 , 2 = 39.21°C).
2. After 4 hr exercise, the mean heart rate for group 2 (164.16 BPM) was significantly higher than group 1 (149.75 BPM) (<0.05).

3. There was no significant difference in the fourth hour skin temperature between the groups ($1 = 36.21$, $2 = 35.96^{\circ}\text{C}$).

4. Blood chemistry and sweat physiology and chemistry could not discriminate between the heat intolerant and heat tolerant subjects.

5. Urinary sodium and chloride concentration was not significantly correlated with the fourth-hour rectal temperature in either group.

6. Sodium and chloride excretion showed a significant negative correlation with temperature at 2 and 4 hr of exercise for group 1, and at 2 hr for group 2.

7. Urinary potassium concentration showed a significant positive correlation with temperature for both groups.

8. Potassium excretion showed a significant negative correlation with temperature at the fourth hour of exercise for group 1, and at the second and fourth hour of exercise for group 2.

Conclusions.

The difference in heat tolerance was found to be due to a difference in salt and water deficit.

116. **Rasch, P. J.; Boyers, J. H.; Hamby, J. W.; and White, P. C., Jr.:**

Evaluation of a Method of Acclimatizing Marines En Route to a Hot-Wet Climate.

U. S. Naval Med. Field Res. Lab. Rept., vol. 17, 1967, pp. 1-13.

Authors' Abstract

One company of troops en route to Vietnam was given vigorous daily exercise in sweat suits in a cargo hold. This produced an increase in body temperature and vigorous sweating. Another company performed similar exercises lightly clad on deck where the environment was cool and where sweating was at a minimum. On arrival in Vietnam the two companies participated in a forced march. The company that had exercised under conditions of heavy sweating performed significantly better than did the company that had trained in a cool environment.

117. **Raven, P. B.; Drinkwater, B. L.; Horvath, S. M.; Ruhling, R. O.; Gilner, J. A.; Sutton, J. C.; and Boldman, N. W.:**

Age, Smoking Habits, Heat Stress, and Their Interactive Effects With Carbon Monoxide and Peroxyacetyl Nitrate on Man's Aerobic Power.

Int. J. Biometeor., vol. 8, 1974, pp. 222-232.

Authors' Abstract

Metabolic, body temperature, and cardiorespiratory responses of 16 healthy middle-aged (40-57 years) men, 9 nonsmokers and 7 smokers, were obtained during tests of maximal aerobic power at ambient environmental temperatures of $25^{\circ} \pm 0.5^{\circ}$ and $35^{\circ} \pm 0.5^{\circ}\text{C}$ and 20% relative humidity under four conditions: (a) filtered air, FA; (b) 50 ppm carbon monoxide in filtered air, CO; (c) 0.27 ppm peroxyacetyl nitrate in filtered air, PAN; and (d) a combination of all three mixtures, PANCO. There was no significant change in maximum aerobic power (\dot{V}_{O_2} max) related to the presence of air pollutants, although total working time was lowered in the 25°C environment while breathing CO. Older nonsmokers did have a decrement in \dot{V}_{O_2} max while breathing 50 ppm CO, while older smokers failed to show any change. This difference was related to the initial COHb levels of the smokers, who, when breathing this level of ambient CO, had only a 14% increase in COHb over their initial levels in contrast to the 200% increase in the nonsmokers. Smoking habits were the most influential factor affecting the cardiorespiratory responses of these older men to maximal exercise. Regardless of ambient conditions, smokers had a significantly lower (27%) aerobic power than nonsmokers, were breathing closer to their maximal breathing capacities throughout the walk, and had

a higher respiratory exchange ratio. While the $\dot{V}O_2$ max of nonsmokers was only 6% less than that of younger nonsmoking males (mean age = 25 yr) working under similar conditions, the aerobic power of the older smokers was 26% lower than that of young smokers (mean age = 24 yr).

118. **Raynaud, J.; Martineaud, J. P.; Bhatnagar, O. P.; Vieillefond, H.; and Durand J.:**
Body Temperatures During Rest and Exercise in Residents and Sojourners in Hot Climate.
Int. J. Biometeor., vol. 20, 1976, pp. 309-317.

Authors' Abstract

Rectal (T_{re}), mean skin temperature (\bar{T}_{sk}), and sweating rate (\dot{S}) were measured in four residents of temperate climate under acute moderate heat exposure (designated EE in such an experimental situation), after 3 weeks in India (designated as EI), and in eight Indian residents (designated as II) both at rest and during submaximal exercises at two different intensities. At rest, T_{re} is higher in EI (37.6°C) than in EE (36.8°C , $P < 0.01$) and reaches 37.8°C in II. At the end of exercise, the increment in T_{re} seems to depend on work load only and to be independent of thermal environment; \dot{S} follows a similar pattern in the three groups of subjects: \bar{T}_{sk} is altered neither by exercise nor acclimatization. Under chronic heat exposure compared to acute conditions: (1) identical \dot{S} is achieved with higher T_{re} and similar \bar{T}_{sk} so that the linear relationship \dot{S} vs T_{re} is shifted to the right; (2) the $T_{re} - \bar{T}_{sk}$ difference is greater at rest and during exercise; hence, skin blood flow, calculated from heat balance equation diminishes. In a hot climate, a rise in T_{re} seems to be an adaptive response which allows the body to reduce skin blood flow.

119. **Roberts, M. F.; Wenger, C. B.; Stolwijk, J. A.; and Nadel, E. R.:**
Skin Blood Flow and Sweating Changes Following Exercise Training and Heat Acclimation.
J. Appl. Physiol.: Respirat. Environ. Exercise Physiol., vol. 43, 1977, pp. 133-137.

Authors' Abstract

Eight subjects underwent an exercise training program (10 days at 75% $\dot{V}O_2$ max for 1 hr/day at 25°C db/ 13°C wb) and a heat-acclimation program (10 days at 50% $\dot{V}O_2$ max for 1 hr/day at 35°C db/ 32°C wb). The relations of chest sweat rate and of forearm blood flow to internal temperature were determined for each subject at a 25°C ambient temperature before training, between training and acclimation, and following acclimation. Training shifted the vasodilation and sweating thresholds toward lower internal temperatures, and acclimation further lowered these thresholds. All threshold shifts were statistically significant ($P < 0.05$). Training and acclimation both appeared to increase the slope of the sweating relation, but these effects were not statistically significant. Changes in the slope of the blood flow relation were small and inconsistent. Since arm blood flow is higher at any given internal temperature after acclimation, the lower blood flow which is reported to accompany heat acclimation must result from the lower body temperatures.

120. **Robinson, S.; Wiley, S. L.; Myhre, L. G.; Bondurant, S.; and Mamlin, J. J.:**
Temperature Regulation of Men Following Heat Stroke.
Israel J. Med. Sci., vol. 12, 1976, pp. 786-795.

Annotation

Purpose. To study the temperature regulation and acclimatization of subjects recovered from heatstroke.

Subjects. Two males recovered from heatstroke; seven male control subjects, four acclimatized and three unacclimatized.

Conditions.

<i>DBT/WBT/RH</i>	<i>Air</i>	<i>kcal/(m²·hr)</i>	<i>Regimen</i>
50°/27°/18%	40 m·min ⁻¹	----	Subject 1 (17 yr): treadmill work for 5 days (mean = 248 kcal/m ² /hr) with testing on days 1 and 5 Subject 2 (28 yr): pre/post test (mean = 190.5 kcal/m ² /hr) on treadmill, with 1 hr daily tennis for 7 wk (30°-34°C)

Subject 1 compared to heat test exercise responses of three unacclimatized and three acclimatized subjects; subject 2 compared to heat test exercise responses of one highly acclimatized subject.

Results.

1. Subject 1 improved only slightly in regulating his central temperature and showed no increase in sweating and evaporative cooling by the fifth day of exposure. Although it was not expected that he would complete acclimatization in 5 days, the authors did not feel that his improvement was as rapid as they had seen in other previous acclimatization studies.
2. In subject 2, temperature regulation and heat tolerance were substantially improved by acclimatization to heat. His sweating and evaporation were 37% higher after acclimatization, but he was not able to achieve the virtually perfect temperature regulation of the highly acclimatized control subject.

121. Rogers, G. G.:

Central Circulatory Changes During Acclimatization to Heat in Man.
So. Afr. Med. J., vol. 47, 1973, p. 961.

Author's Abstract

Cardiac output was determined on four healthy young male subjects at 10 min, 50 min, 110 min, 170 min, and 230 min after commencing exercise on an electronically controlled constant work rate bicycle ergometer (75 W).

Initially these determinations were carried out on three consecutive days in a neutral environment (25°C) and then on each of 10 consecutive days during exposure to heat (32°C wet bulb, 45°C dry bulb, 1.0 m/sec wind velocity).

Cardiac output was calculated from the Fick equation after measuring $P_v\text{CO}_2$ (CO_2 rebreathing method using a rapid response infrared CO_2 analyser), $P\text{aCO}_2$ (Bohr formula), and $V\text{CO}_2$ (open circuit method).

Stroke volume was calculated after measurement of heart rate (cardiotachometer) at the appropriate times. The changes in cardiac output, stroke volume and heart rate demonstrated the adaptation of the central circulation to work in the heat.

122. Rogers, G. G.:

Loss of Acclimatization to Heat in Man During Periods of No Heat Exposure.
So. Afr. Med. J., vol. 52, 1977, p. 411.

Author's Abstract

The rate of loss of acclimatization to heat was investigated in man during periods of no heat exposure following acclimatization.

Five groups of 9-12 subjects were studied. Initially all the subjects of each group performed a standard heat test, which consisted of bench-stepping at a work rate of 35 W (V_{O_2} 1,0 l/min) for a period of 4 hr in an environment of 32.2°C wet bulb 33.9°C dry bulb. Following the standard heat test day the subjects were acclimatized for a period of 7 days. The standard heat test was repeated after acclimatization. From the day following the second standard heat test the subjects were not heat-exposed according to the following schedule: group 1 - 7 days; group 2 - 14 days; group 3 - 21 days; group 4 - 28 days; group 5 - 35 days.

On the day immediately following the last day of the required period of no heat exposure the subjects again performed the standard heat test.

During heat exposure on the test days rectal temperature and heart rate were measured hourly.

The rectal temperature and heart rate response after 4 hours of heat exposure were used as indicators of the level of acclimatization. The physiological adaptations governing heart rate were lost sooner during periods of no heat exposure following acclimatization than those adaptations governing rectal temperature. Fifty per cent of the adaptation governing heart rate and rectal temperature response were lost after about 10 and 15 days of no heat exposure, respectively.

123. Rogers, G. G.; Schutte, P. C.; van Graan, C. H.; and Strydom, N. B.:

A Code of Practice for Heat Tolerance Testing and Micro-Climate Acclimatization.
Chamber of Mines of South Africa Res. Rept. No. 61/77, 1977, pp. 1-17.

Authors' Summary

1. Studies have indicated that the unproductive time spent on climatic room acclimatization by new contractees can be reduced by making use of: (1) the variation in heat tolerance between individuals and (2) a method of heat acclimatization using micro-climate cooling.

2. The highly heat tolerant individual can be identified by subjecting selected groups of incoming labourers to a heat tolerance test (H.T.T.). This test consists of bench-stepping continuously at a work rate, the positive part of which is 54 W (V_{O_2} \pm 1.25 l/min), for a period of 4 hr. The wet-bulb temperature at which the test is performed will depend on the maximal wet-bulb temperature prevailing in a mine, or a particular section of a mine where men are working.

3. Any man who develops an oral temperature of 37.5°C or less during the H.T.T. should be classified as hyper-heat-tolerant. A hyper-heat-tolerant individual can be placed directly on production without the need for further climatic room acclimatization. However, hyper-heat-tolerants should:

- a. Be sent underground not later than the third day after performing the H.T.T.
- b. Not be allocated to working areas with wet-bulb temperatures greater than the wet-bulb temperature at which the H.T.T. was performed for at least 2 weeks
- c. Be encouraged to drink at least 500 ml of water every hour while working underground for the first 2 weeks
- d. Have no restrictions placed on them with regard to job-allocations with the exception that no such man should be allocated to night shift or a development gang during the first 2 weeks

- e. Wear some form of identification during the first 5 days of work underground and be closely supervised by team leaders
- f. Be given a 250 mg vitamin C tablet daily during the first 5 underground shifts following the H.T.T.
- g. Have their oral temperatures recorded before going underground during the first 5 shifts

4. Returnees to mines performing the H.T.T. at a wet-bulb temperature of 31.7°C and who develop an oral temperature of 37.6°C to 38.5°C during the test would be eligible for microclimate acclimatization (M.C.A.). This method of acclimatization involves placing these men directly onto productive work while protected by microclimate suits containing dry-ice as coolant. To allow progression of acclimatization the men performing M.C.A. should be made to work underground at a moderate rate ($\dot{V}O_2$ 0.8–1.4 l/min) for six consecutive full shifts in an environment with a wet-bulb temperature of between 31.7°C and 32.2°C while protected by microclimate cooling. The men performing M.C.A. could:

- a. Be sent underground not later than the third day after performance of the H.T.T.
- b. Be allocated to jobs requiring a moderate rate of energy expenditure provided these jobs do not involve work on night shift or on a development gang
- c. Wear some form of identification
- d. Be encouraged to drink at least 500 ml of water every hour during the shift
- e. Be given a 250 mg vitamin C tablet daily
- f. Have their oral temperature recorded before going underground
- g. Receive underground rates of pay

5. Returnees and novices who develop oral temperatures of 38.6° or above and 37.6°C or above, respectively, during the H.T.T. should continue with the normal vitamin C supplemented climatic room acclimatization procedure. The H.T.T. should count as their respective first day of acclimatization irrespective of the environmental conditions at which the test was performed.

124. Roller, W. L.; and Goldman, R. F.:
 Prediction of Solar Heat Load on Man.
J. Appl. Physiol., vol. 24, 1968, pp. 717-721.

Authors' Abstract

A model is presented for calculating the solar heat load on a man in a given radiant environment. Factors considered include adjustments of surface area for clothing and posture, the absorptance, reflectance, and transmittance of the surface material, and the percentage of absorbed solar heat actually reaching the skin. Average maximum calculated values of solar heat loads were 400 kcal/hr for a nude tanned Caucasian, 500 kcal/hr for a nude Negroid, 200 kcal/hr when wearing a military fatigue uniform, and 125 kcal/hr when wearing heavier clothing.

125. Rowell, L. B.; Brengelmann, G. L.; Blackmon, J. R.; Twiss, R. D.; and Kusumi, F.:
 Splanchnic Blood Flow and Metabolism in Heat-Stressed Man.
J. Appl. Physiol., vol. 24, 1968, pp. 475-484.

Authors' Abstract

To determine whether normal splanchnic metabolism could be maintained during prolonged thermal and exercise stresses which reduced hepatic blood flow (HBF), HBF was estimated in 11 men who worked to exhaustion at 42–56% of maximal $\dot{V}O_2$ at 48.9°C. HBF was low (average 667 ml/min) but quite stable throughout exercise despite falling peripheral pulse pressure. Temperatures rose to 40.2°C in the rectum and 41.7°C in hepatic veins at exhaustion. Total $\dot{V}O_2$ rose slightly

during work while splanchnic \dot{V}_{O_2} rose 1.4 times. Hepatic venous oxygen content fell to 0.6 ml/100 ml. Hepatic glucose release increased from 351 mg/min at 10 min to 749 mg/min at exhaustion. Uptake of FFA was normal at 0.13 meq/min. Arterial lactate rose abnormally high; hepatic extraction percentage was 58% of normal with net release in two men at exhaustion. Glucose outpouring and elevated hepatic venous lactate concentrations suggest developing hepatic-splanchnic hypoxia.

126. Schmauz, R.; and Höfler, W.:

Pulsfrequenz, Kerntemperatur, Wasser und Elektrolytstoffwechsel bei 10 monatigem Aufenthalt in natürlichem Tropischem Klima. (Pulse Rate, Core Temperature, Water and Electrolyte Metabolism During a Ten Months' Stay in a Natural Tropical Climate.)

Z. Tropenmed. Parasit., vol. 20, 1971, pp. 364-373.

Authors' Summary

The aim of this study was the observation of the "naturally" acquired state of acclimatization in a physically fit European (26 yr, 194 cm, 87 kg) living in the humid tropics of Abeokuta SW-Nigeria from Jan. 17 through Nov. 15, 1967. Water, sodium and potassium excretion in urine were measured every second day, commencing on Jan. 22. Total body sweat loss, sweat collected from both forearms and legs in plastic bags, resting and working pulse rates and oral temperatures were determined during moderate work with a bicycle ergometer (10 m kp/sec for 40 min = 5.6 kcal/min) twice weekly commencing on Feb. 4. Between March 20 and April 28, the period of the most severe climate load, the experiments were interrupted because of illness. The data obtained were submitted to regression analysis; they proved to be intercorrelated and dependent on the dry-bulb temperature taken at the beginning of the working test. In relation to the equivalent temperature, however, similar results were found only for the sweat rates. According to previous experiments it must be assumed that this system of correlations was established during the first 3 weeks after arrival, remaining unchanged during the following 9 months.

The values recorded under similar climatic conditions at the beginning and end of the rainy season indicate the possibility of a certain loss of acclimatization during the cooler months (increased body temperatures, pulse rates, urine volume, sodium excretion, and decreased sweat rates, potassium excretion), although the differences for each value alone were not significant. Thus, to elucidate this question a more detailed statistical analysis will be required.

The role of core temperature as the first link in the reaction chain of the physiological responses to heat studied is discussed.

127. Sciaraffa, D.; Shvartz, E.; Keil, L. C.; Brock, P. J.; and Greenleaf, J.E.:

Heat Acclimation and Resting Blood Pressure of Normotensive Men.

Med. Sci. Sports, vol. 9, 1977, p. 51.

Authors' Abstract

To determine the effect of heat acclimation on blood pressure, five healthy normotensive men (21-24 yr) were acclimated to heat by eight exposures of bicycle ergometer exercise (50% \dot{V}_{O_2} max, 2 hr daily) at 39.8°C DB, 30.0°C WB. Five male control subjects (19-22 yr) underwent the same procedure at 24°C. Heart rates (HR) and indirect sphygmomanometric blood pressures (BP) were recorded each day before exposure, and venous antecubital blood samples were taken on days 1, 2, 4, and 8. Heat acclimation resulted in the usual decreases in exercise HR, rectal and skin temperatures, and an increase in sweat rate, while the control group showed effects of training by decreases in exercise HR and rectal temperature. The acclimation group exhibited the following mean changes ($*P < 0.01$) in resting HR (beats/min) and BP (mm Hg) from day 1 to day 8: 57 to 49* and 121/84 to 121/73* in recumbency; 61 to 54* and 122/94 to 122/85* during sitting; and 66 to 64 and 124/97 to 123/87* while standing. The corresponding changes in the control group were negligible.

There were no significant changes in resting plasma vasopressin or renin activities during acclimation or training. The significant 10 mm Hg decreases in diastolic BP after acclimation were probably a result of increased stroke volume and decreased peripheral resistance. Thus, training in hot, instead of cool conditions, may present an effective method for lowering BP.

128. **Senay, L. C., Jr.:**

Changes in Plasma Volume and Protein Content During Exposures of Working Men to Various Temperatures Before and After Acclimatization to Heat: Separation of the Roles of Cutaneous and Skeletal Muscle Circulation.

J Physiol. (London), vol. 224, 1972, pp. 61-81.

Author's Summary

1. Ten male subjects were trained in stair stepping for 2 weeks. Group A (six subjects) was thereupon sequentially exposed for 45 min to dry bulb temperatures of 20°, 40° and 30°C, a vapor pressure of 10-11 mm Hg and a wind speed of 1 m/sec in a climate tunnel. While temperature changes were being effected the subjects rested in an antechamber. Group B (four subjects) was exposed to a sequence of 40°, 20° and 30°C. Work rate was the same for all subjects, i.e. 216 kg m/min (\approx) to an oxygen consumption of 0.9 l/min). Duplicate experiments were run on both groups of subjects before and after acclimatization to heat.

2. Throughout, periodic samples of venous blood, water and protein movement into or out of the extravascular compartment was assessed during exercise periods wherein blood flow was increased to exercising muscles (Group A, 20°C) or to both exercising muscles and skin (Group B, 40°C; Groups A and B, 30°C.)

3. Mild exercise in a cool environment before and after acclimatization to heat was accompanied by expansion of the vascular volume and an increase in the amount of circulating protein.

4. Mild exercise in a warm environment for 45 min was accompanied by hemoconcentration and loss of protein from the vascular volume before subjects were heat acclimatized. The results were reversed following heat acclimatization; i.e., exposure of Group B to 40°C and of Groups A and B to 30°C was accompanied by hemodilution and addition to (or maintenance of) plasma protein concentration.

5. Effects of heat acclimatization on exposure of Group A to 40°C were also noted.

6. The effects of heat acclimatization were ascribed to: (1) a change in permeability of cutaneous capillaries to large molecules, (2) an increased availability of translocatable protein within cutaneous interstitial spaces, and (3) combination of (1) and (2).

7. Further, the results supported a previous suggestion that addition or loss of water and protein from the vascular volume is dependent on the ratio of cutaneous to muscle blood flow.

129. **Senay, L. C., Jr.:**

Plasma Volumes and Constituents of Heat-Exposed Men Before and After Acclimatization.

J. Appl. Physiol., vol. 38, 1975, pp. 570-575.

Author's Summary

Five men underwent a 2-week exercise regimen and were then exposed to 45°C db, 28°C wb, wind speed 1 m/sec for 12 hr while at rest. Body weight was maintained with 0.1% saline. One week later the exposure was repeated without rehydration. After heat acclimatization, the 12-hr experiments were repeated. Frequent body weights, rectal temperatures, and venous blood samples were obtained. Results indicated that hemodilution upon acute heat exposure is partially due to protein influx into the vascular volume and the hemodilution allowed considerable loss of body water before plasma volume returned to preexposure values. Water within the vascular volume appeared to

be in equilibrium with that in other body compartments before but not after acclimatization. Acclimatization altered the rate of protein transfer (and water movement) such that hemodilution was accomplished more rapidly than before acclimatization. Early hemodilution was quite labile and depended upon subject hydration during the first hour of heat exposure.

130. **Senay, L. C.; and Kok, R.:**

Body Fluid Responses of Heat Tolerant and Intolerant Men to Work in a Hot Wet Environment.

J. Appl. Physiol., vol. 40, 1976, pp. 55-59.

Authors' Abstract

Acclimatization to heat before proceeding underground is a requirement for each South African mine laborer. Certain individuals among this large population cannot be acclimatized to heat (33.3°C db, 31.7°C wb) and are classified as heat intolerant. In this study certain body fluid responses to heat and work were compared between a group of 19 heat-tolerant (HT) and a group of 15 heat-intolerant* (HI) subjects. To the factors known to affect heat tolerance, such as age, weight, and oxygen consumption, must now be added differences in body fluid responses. The HI group of subjects failed to hemodilute to the same degree as the HT group though working at the same relative work loads (30% and 50% $\dot{V}\text{O}_2$ max). As the 4-hr work period (33.3°C db, 31.7°C wb) continued, the HI group did not maintain hemodilution in spite of the lower absolute work loads, sweat rates, and water deficits suffered by this group. From analysis of blood constituent changes it was suggested that the reason for the differences noted in body fluid dynamics concerned plasma protein equilibrium across capillary walls as well as the protein population of interstitial spaces.

131. **Senay, L. C.; and Kok, R.:**

Effects of Training and Heat Acclimatization on Blood Plasma Contents of Exercising Men.

J. Appl. Physiol.: Respirat. Environ. Exercise Physiol., vol. 43, 1977, pp. 591-599.

Authors' Abstract

Five men trained 4 hr/day for 43 days with increasing work loads on bicycle ergometers. Maximum oxygen consumption ($\dot{V}\text{O}_2$ max) and lactate turn points ($\dot{V}\text{O}_2$ at which lactate production increases exponentially) were assessed before, during and after training. Following training the subjects were acclimatized to heat. A 4-hr work test (stepping at 35 W) was done in a cool (18° - 22°C) environment before training began, at intervals during training, and after acclimatization. The test was also repeated in a hot environment (33.8°C db, 32.4°C wb) before and after training and acclimatization. During each test, mean skin temperature (T_{sk}), rectal temperature (T_{re}), body weights, $\dot{V}\text{O}_2$, and blood samples were obtained. Training had little effect on thermoregulation during cool tests but did modify thermoregulatory mechanisms early in heat exposure. Work tests done in a cool environment were accompanied by hemoconcentration before and hemodilution after 3 weeks of training. Protein dynamics and improvement in muscle metabolism appeared to contribute to the shift from hemoconcentration to hemodilution. Training stabilized plasma volume during a heat exposure but acclimatization afforded further protection against heat stress because of increased hemodilution and sensitivity of the sweat mechanism.

132. Senay, L. C.; Mitchell, D.; and Wyndham, C. H.:
Acclimatization in a Hot, Humid Environment: Body Fluid Adjustments.
J. Appl. Physiol., vol. 40, 1976, pp. 786-796.*

Authors' Abstract

Four trained men worked 4 hr/day at 40-50% of their maximum aerobic capacity first for 3 days at 25°C db, 18°C wb and then for 10 consecutive days at 45°C db, 32°C wb. Between days 1 and 2 of heat exposure mean total circulating protein (TCP) and plasma volume (PV) increased 11.6% and 9%, respectively. Preexposure TCP and PV increased until day 6 of heat exposure. Of the protein fractions β -globulins underwent the largest relative increase. During work, movement of protein into and out of the vascular compartment was similar in control and acclimatizing subjects but the latter generally maintained a greater amount of protein and fluid within the vascular volume. There was no evidence of salt and water retention. The increase in vascular volume was ascribed to transfer of interstitial protein and water to the vascular volume. Regression coefficients indicated significant correlations for changes in plasma volume versus heart rate, stroke volume, and cardiac output during acclimatization. It was concluded that the most critical event in heat acclimatization is the expansion of the plasma volume.

133. Shvartz, E.; and Benor, D.:
Heat Acclimatization by the Prevention of Evaporative Cooling.
Aerospace Med., vol. 42, 1971, pp. 879-881.

Authors' Abstract

The effect of a heat-acclimatization program was assessed in five male subjects by a work-heat test (5 km/hr; 50°C; 20% relative humidity). The acclimatization program included four exposures to 40°C, over a period of 2 weeks, during which the men walked on a treadmill at a speed of 3.5 km/hr while wearing vapor-barrier suits. Acclimatization resulted in final mean heart rate, rectal temperature, skin temperature, and sweat rate of 125 beats/min, 37.8°C, 37.7°C, and 0.918 kg/hr, respectively. Three of the subjects, whose pre-acclimatization values were compared, showed mean heart rate, rectal temperature, skin temperature and sweat rate decreases of 21 beats/min, 1.0°C, 0.1°C and 0.113 kg/hr, respectively. Sweat rate, expressed as per-degree-rise in rectal temperature, about doubled. These results suggest that preventing evaporative cooling presents a major factor in heat acclimatization.

134. Shvartz, E.; Benor, D.; and Saar, E.:
Natural Acclimatization to Work in Severe Heat.
Aerospace Med., vol. 43, 1972, pp. 637-640.

Annotation

Purpose. To determine the natural acclimatization of young untrained men to work in severe heat.

Subjects. Eleven untrained males, mean age 23 yr, weight 68.1 kg, height 175 cm, body surface 1.83 m².

*Same as: Senay, L. C., Jr.; Mitchell, D.; and Wyndham, C. H.: Plasma Protein and Volume Changes During Heat Acclimatization, *Physiologist*, vol. 16, 1973, p. 446.

Conditions.

<i>DBT/WBT/RH</i>	<i>Air</i>	<i>kcal/(m²·hr)</i>	<i>Regimen</i>
50°C, 28-30°C, 20-24%	25 m/min	---	90 min treadmill walking, 5.6 km/hr, 5% grade, once during summer, and once during winter Ad libitum water intake, exercise terminated at HR 190 BPM or T_{re} 39.5°C.

Results and conclusions.

The average exercise tolerance time was 65 min in winter and 67 min in summer. Mean heart rates decreased from 176 BPM in winter to 168 BPM in summer (-8 BPM, $P < 0.05$) while mean T_{re} did not alter significantly. In the summer, mean T_{sk} decreased ($P < 0.01$) from 39.2° to 38.1°C and sweat rate increased by 13% from 0.649 to 0.737 $\ell/(m^2 \cdot hr)$ (+0.088, $P < 0.05$). Tolerance times increased in four subjects, remained unchanged in four, and decreased in three. Only two subjects showed improvements with artificial acclimatization equal to known improvements with artificial acclimatization. It was concluded that work in severe heat is not substantially affected by seasonal changes.

135. Shvartz, E.; Benor, D.; and Saar, E.:

Acclimatization to Severe Dry Heat by Brief Exposures to Humid Heat.

Ergonomics, vol. 15, 1972, pp. 563-571.

Authors' Abstract

Fourteen subjects underwent a work heat test (walking for 90 min at 5.6 km/hr up a 5% gradient at 50°C with 20% relative humidity) before and after a 4-day acclimatization program. For the control group (7 subjects) this program included a 50-min walk on the level at 3.5 km/hr at 40°C with 20% relative humidity for 4 consecutive days. The experimental group (7 subjects) underwent the same acclimatization program while wearing rubber suits that simulated an environment of near 100% relative humidity. Acclimatization in the experimental group showed a mean decrease in heart rate, rectal temperature, and skin temperature of 26 beats/min, 0.6°C, and 1.7°C, respectively. Sweat rate increased 63% for any given rise in rectal temperature. The control group showed less than half the improvement in physiological responses exhibited by the experimental group. It was concluded that exposure to extreme humid heat enables rapid acclimatization to severe dry heat.

136. Shvartz, E.; Benor, D.; and Saar, E.:

Effect of Acclimatization to Severe Heat on Energy Expenditure.

Israel J. Med. Sci., vol. 8, 1972, p. 1016.

Authors' Abstract

The present study was conducted to determine the metabolic changes occurring during acclimatization to severe heat. Ten healthy male subjects were given a work-heat test that included an attempt to walk for 90 min at a speed of 5.6 km/hr up a 5% slope at a room temperature of 50°C with 20% relative humidity. This test was given four times: in winter before and after a short acclimatization program, and again in summer before and after the same acclimatization program. O₂ consumption, pulmonary ventilation and heat strain measurements were recorded. No significant changes in O₂ consumption occurred during the acclimatization, in either winter or summer. However, O₂ consumption was significantly reduced, by 11%, from the preacclimatization condition in winter to the

postacclimatization condition in summer. The decrease in $\dot{V}O_2$ consumption on acclimatization followed a pattern similar to heart rate changes; a tendency for high initial values to show larger decreases and vice versa. It was concluded that acclimatization to severe heat results in a decrease in submaximal $\dot{V}O_2$ consumption.

137. Shvartz, E.; Bhattacharya, A.; Sperindi, S. J.; Brock, P. J.; Sciaraffa, D.; Haines, R. F.; and Greenleaf, J. E.:
 Heat Acclimation and Water-Immersion Deconditioning: Responses to Exercise.
Aerospace Med. Assoc. Preprints, 1977, pp. 11-12.

Annotation

Purpose. To determine the effects of heat acclimation and moderate physical training, performed in cool conditions, on water-immersion deconditioning.

Subjects. Ten males (mean age 21.4, mean height 178.2 cm, mean weight 76.1 kg, mean body surface area $19.35m^2$, mean $\dot{V}O_2$ max $3.15 \ell/min$).

Conditions.

DBT/WBT/RH	Air	kcal/($m^2 \cdot hr$)	Regimen
39.8/30.0/50%	----	----	Five subjects (heat acclimation)
23.8/17.0°/50%	----	----	Five controls (training)

Procedure:

Day 1, 10, 12:	Max $\dot{V}O_2$ test, supine position
Days 2-9:	Training in respective environments on upright bicycle ergometer, 2 hr/day, 50% $\dot{V}O_2$ max
Day 11:	8-hr water immersion

Results.

1. Exercise tolerance. Heat acclimation resulted in decreases of about 4 BPM in resting ($P < 0.05$), submaximal (N.S.), and maximal (N.S.) heart rates. Comparable changes in the control group were negligible and nonsignificant.

Heat acclimation resulted in significant ($P < 0.05$) increases of 3.8% in $\dot{V}O_2$ max and 5% in the maximal load tolerated. The control group showed a nonsignificant increase in $\dot{V}O_2$ max and no change in the maximal load tolerated.

2. Water-immersion. Compared with preacclimation values, post-water-immersion responses of the acclimation group were not significantly different, except for resting heart rate. The corresponding differences in the control group were all adverse, although differences in resting heart rate and $\dot{V}O_2$ max were not significant. Both procedures resulted in adverse responses when post-water-immersion values were compared with post-acclimation or post-training responses. These adverse responses in the acclimation group were significantly different only for the maximal load tolerated, while in the control group, the responses were significantly different for all parameters except $\dot{V}O_2$ max.

Conclusion.

Heat acclimation can essentially prevent the adverse effects of water-immersion deconditioning on exercise tolerance.

138. Shvartz, E.; Bhattacharya, A.; Sperindji, S. J.; Greenleaf, J. E.; Brock, P. J.; Sciaraffa, D.; and Van Beaumont, W.:
Sweating Responses During Heat Acclimation and Moderate Training.
Proc. 27th Int. Union Physiol. Sci., vol. 13, 1977, p. 694.

Authors' Abstract

To compare sweating responses during heat acclimation and moderate training, five young men ($\dot{V}O_2$ max, 3.1 l/min) underwent 8 days of heat acclimation (bicycle ergometer work at 50% of $\dot{V}O_2$ max, 2 hr daily, at 39.8°C DB, 30.0°C WB), and five young men with the same $\dot{V}O_2$ max underwent the same procedure at 24°C. Acclimation resulted in decreases in heart rate, rectal temperature (T_{re}), and oxygen consumption of 30 beats/min, 0.7°C and 7%, respectively. The corresponding changes during training at 24°C were 10 beats/min 0.25°C, and 7%. Whole body sweat rate (SR) increased 19% during acclimation and decreased 24% during training. Water intake increased 100% from the first to eighth day during acclimation, with no significant changes occurring on training. Acclimation resulted in earlier onset, and an increase in the rate of change of sweating and an increase in SR per °C rise in T_{re} . Training resulted in a delay in onset, and a decrease in the rate of change of sweating, and in negligible changes in SR per °C rise in T_{re} . Both acclimation and training resulted in the highest SR mg/cm²/min on the arm and the lowest on the thigh (1.1 – 1.75 in heat; 0.28 – 0.35 at 24°C). Acclimation resulted in a larger increase in SR on the thigh and arm than on the chest, while training resulted in a larger decrease in SR on the chest than on the thigh and arm. The results indicated that heat acclimation and moderate training result in almost opposite sweating responses.

139. Shvartz, E.; Magazanik, A.; and Glick, Z.:
Thermal Responses During Training in a Temperate Climate.
J. Appl. Physiol., vol. 36, 1974, pp. 572–576.

Authors' Abstract

Five young men underwent a daily training program consisting of bench-stepping at a load equal to 85% of their $\dot{V}O_2$ max, at 21.5°C db; 17.5°C wb, for 12 days. Physiological and thermal responses were recorded each day. A comparison between the first and last days showed decreases in heart rate, submaximal $\dot{V}O_2$, and percent fat of 35 beats/min, 16%, and 1.1%, respectively, and increases in $\dot{V}O_2$ max and fat-free body weight of 16% and 1 kg, respectively. Resting and exercise rectal temperatures, skin temperature, sweat rate, and conductance decreased 0.2°C, 0.4°C, 0.6°C, 23%, and 14%, respectively. These changes corresponded to decreases in heat production, evaporation, and heat storage. The decrease in exercise rectal temperature on training resulted from the decreases in metabolism and in resting rectal temperature. Most of the changes occurred during the first 4–5 days. The results indicate that training in a temperate climate results in an increase in thermal economy and efficiency.

140. Shvartz, E.; and Meyerstein, N.:
Effect of Heat and Natural Acclimatization to Heat on Tilt Tolerance of Men and Women.
J. Appl. Physiol., vol. 28, 1970, pp. 428–432.

Authors' Abstract

Eighteen young men and 18 young women were given a 20-min tilt-table test and a 10-min bicycle ergometer test in a temperate (24°C) and in a hot (40°C) climate in the summer and winter seasons of a semidesert environment. The winter-heat tests resulted in the greatest number of faintings, and in more adverse orthostatic symptoms in comparison with the other tests. The summer-heat tests resulted in only about half of these symptoms. Positive relationships were found between exercise heart rates in heat and orthostatic heart rates in heat, and between exercise and orthostatic heart

rates in acclimatized and nonacclimatized subjects. No differences were found between the men's and women's orthostatic reaction to heat and season. These findings suggest that tilt tolerance can effectively represent reaction to heat and heat acclimatization.

141. Shvartz, E.; Saar, E.; and Benor, D.:
Physique and Heat Tolerance in Hot-Dry and Hot-Humid Environments.
J. Appl. Physiol., vol. 34, 1973, pp. 799-803.

Authors' Abstract

Twenty-five young men, with surface area/weight (SA/w) ratios varying by as much as 28% ranging from 2.32 to 3.07, underwent several work-heat tests to determine the relationship between physique and heat tolerance. All 25 subjects were tested in dry heat of 50°C, and of these 8 subjects were tested at 30°, 35°, and 45°C while wearing vapor-barrier suits that covered the entire body and prevented the evaporation of sweat. In dry heat, subjects with high SA/w ratios produced 12% less heat than subjects with low ratios, but heat strain was not substantially different between the two groups and the relationship between SA/w ratio and heat tolerance was low ($r = -0.22$). The humid-heat experiments revealed: that at 30°C, subjects with high SA/w ratios were distinctly superior in heat tolerance to subjects with low ratios; and that at 35°C the relationship between SA/w ratio and heat tolerance was low ($r = -0.31$), and at 45°C it was negligible ($r = 0.14$). The results were explained in terms of differences in heat production and heat loss between subjects with low and high SA/w ratios.

142. Shvartz, E.; Saar, E.; Meyerstein, N.; and Benor, D.:
Heat Acclimatization While Wearing Vapor-Barrier Clothing.
Aerospace Med., vol. 44, 1973, pp. 609-612.

Authors' Abstract

Acclimatization to a hot, humid environment was studied in nine men who performed moderate work at an air temperature of 37°C while wearing vapor-barrier suits, for 6 successive days. Heart rate, rectal, and skin temperatures, sweat rate and oxygen consumption were recorded. The results showed only partial acclimatization, which was indicated by decreases in heart rate and in rectal and skin temperatures of 16 beats/min, 0.5°C, and 0.6°C, respectively, from the first to the sixth exposures. Sweat rate increased 25%, oxygen consumption decreased 13%, and resting rectal temperature decreased by 0.3°C. These changes made possible an increase of 13 min in tolerance time. Since the evaporation of sweat was minimal, due to the vapor-barrier suits, acclimatization was attributed to the lowering of resting body temperature and to the decrease in heat production.

143. Shvartz, E.; Saar, E.; Meyerstein, N.; and Benor, D.:
A Comparison of Three Methods of Acclimatization to Dry Heat.
J. Appl. Physiol., vol. 34, 1973, pp. 214-219.

Authors' Abstract

A work-heat test (50°C DB, 28°C WB; 5.6 km/hr up a 5% grade) was given to three groups of subjects following three programs of acclimatization: by exposure to dry heat (6 subjects), wet heat of equal stress (6 subjects), and exercise performed at an air temperature of 23°C (5 subjects). Each program lasted 60-90 min daily, for 6 consecutive days. The hot-dry and the hot-wet groups performed mild work during acclimatization (1.0 l/min of oxygen), while the exercise group performed hard work (1.9 l/min of oxygen). The performance of the three experimental groups in the work-heat test was compared with results obtained on 14 unacclimatized subjects (control group). The three experimental groups showed a reduction in heart rate, rectal and skin temperatures, and

metabolism, and an increase in sweat rate from the first to the sixth day of acclimatization, the hot-dry group displaying the largest changes. A comparison between the three experimental groups and the control group on the work-heat test showed substantial acclimatization in the hot-dry group, mild acclimatization in the hot-wet group, and a lack of acclimatization in the exercise group. It was shown that acclimatization to dry heat resulted from a decrease in resting body temperature and an increase in the efficiency, rather than the quantity of sweating, and that these changes were accompanied by decreases in work metabolism and in heat conductance.

144. Shvartz, E.; Shapiro, Y.; Magazanik, A.; Meroz, A.; Birnfeld, H.; Mechtinger, A.; and Shibolet, S.:

Heat Acclimation, Physical Fitness, and Responses to Exercise in Temperate and Hot Environments.

J. Appl. Physiol.: Respirat. Environ. Exercise Physiol., vol. 43, 1977, pp. 678-683.

Authors' Abstract

Three groups of men with different $\dot{V}O_2$ max (60.1, 47.7, and 35.6 ml/kg/min) were administered two submaximal tests at 23°C, at 41 and 82 W, before and after 8 days of heat acclimation (3-hr work at 41 W at 39.4°C dry bulb, 30.3°C wet bulb). A control group with $\dot{V}O_2$ max of 45.3 ml/kg/min was tested at 23°C and in heat before and after 6 days of exercise at 23°C. Trained subjects with the highest $\dot{V}O_2$ max showed the best responses, and the lowest $\dot{V}O_2$ max group showed the worst responses at 23°C and in heat (differences in heart rates and rectal temperatures but not in sweat rates and oxygen consumption responses). Heat acclimation resulted in substantial improvements in responses at 23°C and in heat of the acclimation groups, with very minor changes shown by the control group. Changes at 23°C were characterized by decreases in heart rate, rectal temperature (0.3°-0.5°C), oxygen consumption, and sweat rate (25-30%), and increases of 13% and 23% in $\dot{V}O_2$ max in the groups with average and low $\dot{V}O_2$ max, respectively. $\dot{V}O_2$ max correlated $r = -0.62$ and -0.65 with rectal temperatures at 23°C and in heat, respectively. It was shown that exercise rectal temperature at 23°C was mainly a function of heat acclimatization, as well as $\dot{V}O_2$ max and surface area/mass ratio, that heat acclimation presented an effective method of physical training, and that $\dot{V}O_2$ max was partially related to heat tolerance.

145. Shvartz, E.; Strydom, N. B.; and Kotze, H.:

Orthostatism and Heat Acclimation.

J. Appl. Physiol., vol. 39, 1975, pp. 590-595.

Authors' Abstract

Three groups of subjects (six in each group) underwent the following procedures: *group A* was given a 20-min head-up tilt at 21°C followed by 4 hr of exercise at 33.9°C DB, 32.2°C WB, and a repetition of tilting after exercise in heat; *group B* underwent the same procedure at 21°C; *group C* was tilted at 21°C, rested in heat for 4 hr and was retilted in heat. The above procedures were repeated for 8 days, and on the last day *groups B* and *C* underwent the same treatment as *group A*. *Group A* showed the usual decreases in heart rate and rectal temperature and an increase in sweat rate on acclimation.. This corresponded to marked improvements in heat-orthostatism. Although five subjects in *group A* fainted during post-exposure tilting on the first exposure, none fainted on the last day. Resting in heat (*group C*) did not cause any acclimation to work in heat. This corresponded to poor heat-orthostatism after the work-heat procedure when five subjects fainted. Mild training at 21°C (*group B*) resulted in minor improvements to work in heat as evident by some improvements in heart rate responses after the first and second hour of exposure. This corresponded to better heat-orthostatism and fewer men fainting than in *group C*. The results indicated that heat-orthostatism improves on acclimation to the same extent as exercise heart rate and rectal temperature.

146. Smiles, K. A.; and Robinson, S.:
Sodium Ion Conservation During Acclimatization of Men to Work in the Heat.
J. Appl. Physiol., vol. 31, 1971, pp. 63-69.

Authors' Abstract

Changes in Na^+ output by the kidneys and sweat glands of five men were investigated during acclimatization by seven daily 100-min periods of treadmill work (5.6 km/hr) in the heat (45°C db, 23°C wb), under two conditions of salt intake. During acclimatization on a low-salt diet in which Na^+ deficits of 140-320 meq were incurred, the renal and sweat Na^+ outputs were greatly reduced, plasma Na^+ concentration fell, and daily urinary tetrahydroaldosterone (THA) was increased by 3-6 times control values. In this condition of salt deficiency with attendant water deficit, the subjects had lower sweat rates, lower skin temperatures, higher rectal temperatures, and lower coefficients of tissue heat conductance than during acclimatization with replacement of salt and water. During acclimatization with replacement of sweat Na^+ and water losses, the subjects stored Na^+ and had reduced hematocrits, suggesting an expansion of the plasma volume, which took place without an increase in urinary THA excretion; there were no significant changes in urinary Na^+ output and three of the men showed no reduction in sweat Na^+ concentration. Two subjects with initially higher sweat Na^+ concentrations showed small reductions in their sweat Na^+ concentrations to the lower more constant levels of the other subjects. Thus the data indicate that the full Na^+ -conserving responses of kidneys and sweat glands during acclimatization of men to work in the heat must be dependent on Na^+ deficiency with attendant after deficit, reductions in extracellular fluid volume and $[\text{Na}^+]$, and increased mineralocorticoid activity.

147. Strydom, N. B.:
Age as a Causal Factor in Heat Stroke.
J. So. Afr. Inst. Min. Metall., vol. 72, 1971, pp. 112-114.

Author's Summary

The data on heat stroke cases reported during the past 5 years were examined to determine the influence of age on the incidence of heat stroke. Relating the age distribution of these cases to that of the total number of Bantu mine workers showed clearly that the older men run a significantly higher risk of developing heat stroke than the younger men. Although the number of Bantu over 40 yr of age in the industry is less than 10% of the total, they nevertheless accounted for 50% of the fatal heat stroke and 25% of the nonfatal heat stroke cases during the period under review. Age must, therefore, be recognized as a causal factor in heat stroke and the worker over 40 yr of age should be allocated to work on surface, or in cool areas or to nonstrenuous and supervisory tasks in hot areas.

148. Strydom, N. B.; Benade, A. J. S.; Swanepoel, H. J.; and Heyns, A. J. A.:
A Comparison of the Effectiveness of Five-, Seven-, Eight-, and Nine-day Acclimatization Procedures.
J. So. Afr. Inst. Min. Metall., vol. 72, 1971, pp. 105-107.

Authors' Summary

Groups of up to 12 new recruits to the industry were subjected to climatic room acclimatization for either 5, 7, 8, or 9 days prior to being tested for the degree to which they had been acclimatized. These tests were done at 32.2°C (wet bulb) at a wind velocity of about 0.4 m/sec, and the men worked for 4 hr at a rate of 215.6 kg m/min on one day and at a rate of 431.2 kg m/min on the second day. The results indicated that there is no significant difference between the degrees of acclimatization obtained by the 8- and 9-day procedures, which confirms the conclusions drawn in a

previous report. The 8-day procedure can thus be claimed to be perfectly adequate and safe. Decreasing the period of exposure to 5 or 7 days would however, not be justified because of the significant differences in physiological responses that were observed on both test days between men acclimatized for these periods and those acclimatized for 9 days. It is concluded that it would be unsafe to employ these shorter periods of acclimatization when underground environmental temperatures at which the men are to work exceed 31°C (wet bulb).

149. Strydom, N. B.; Benade, A. J. S.; and van der Walt, W. H.:

The Influence of Two Weeks of Microclimate Cooling on the State of Heat Acclimatization.
J. So. Afr. Inst. Min. Metall., vol. 75, 1975, pp. 319-321.

Authors' Summary

Five volunteer black subjects were acclimatized according to the climatic-room acclimatization procedure, and their states of heat acclimatization were determined by the usual heat-stress test. The subjects thereafter wore pre-frozen jackets in a somewhat higher environmental temperature (33.9°/35.6°C), stepping at the same rate as before for 4 hr/day for 14 days. The heat-stress test was repeated and followed by a similar test at the higher environmental temperature.

It was found that 14 days of microclimate cooling in a very hot environment had no adverse effect on the degree of heat acclimatization. The sweat rates during microclimate cooling remained high, even though no sweating is possible beneath the pre-frozen ice-jacket, which indicates that there is an increase in sweat rate from the areas of exposed skin.

150. Strydom, N. B.; and Holdsworth, L. D.:

The Effects of Different Levels of Water Deficit on Physiological Responses During Heat Stress.

Int. Z. Angew. Physiol., vol. 26, 1968, pp. 95-102.

Authors' Summary

The influence of different levels of water deficit on the physiological responses to heat stress of two well-acclimatized subjects was studied. The subjects worked continuously at a rate of 2,000 ft lb/min for 4 hr at 32.2°C W.B., 33.9°C D.B. and an air velocity of 0.25 – 0.4 m/sec. Man, even when in water deficit, operates most efficiently when he replaces all the fluids lost in sweat and urine by drinking water in small amounts at frequent intervals. When a specific level of water deficit is maintained throughout the 4 hr of heat exposure, body temperature, heart rate, and sweat rate reach equilibrium at values that are significantly different from those recorded under conditions of complete water balance; the more severe the level of dehydration the higher the body temperatures and heart rates, and the lower the sweat rates. No indication of any failure of the temperature regulating mechanisms or fatigue of the sweat glands was found and a possible explanation for this difference with previously reported results is provided.

151. Strydom, N. B.; Kok, R.; Jooste, P. L.; and van der Walt, W. H.:

Intermittent Exposures to Heat, and the Retention of Heat Acclimatization.
J. So. Afr. Inst. Min. Metall., vol. 75, 1975, pp. 315-318.

Authors' Summary

Twenty-one heat acclimatized subjects were assessed for the degree of acclimatization attained with respect to heart rate, rectal temperature, and sweat rate during a standard 4 hr heat-stress test. Thereafter, they were put on light duties in cool environments for 4 weeks, except for 4 hours of exposure to heat every seventh day. Their state of heat acclimatization was again assessed 2 days

after the final week's exposure. Although heart rates and body temperatures showed significant increases over the initial values, no differences were observed in sweat rates, and, in general, the subjects were rated as still adequately acclimatized to heat.

152. **Strydom, N. B.; Kotze, H. F.; van der Walt, W. H.; and Rogers, G. G.:**
Effect of Ascorbic Acid on Rate of Heat Acclimatization.
J. Appl. Physiol., vol. 41, 1976, pp. 202-205.

Authors' Abstract

There is some indication in the literature that ascorbic acid (vitamin C) may reduce the physiological responses to heat stress. Consequently, the effect of ascorbic acid ingestion on heat-strain indicators has been studied on a group of 60 mining recruits undergoing climatic room acclimatization. Of the 60 men, 19 received a daily dose of 250 mg ascorbic acid; 21 a daily dose of 500 mg ascorbic acid; and 20 received a placebo daily. Measurements of rectal temperature, heart rate, and hourly sweat rate were made on all subjects during the 4 hr/day heat exposure for 10 days. The wet bulb temperature was 32.2°C, the dry bulb 33.9°C, the air movement 0.4 m/sec, and the work rate 35 W. The results indicate that the rate and degree of acclimatization, as assessed by fourth-hour rectal temperature, is enhanced by ascorbic acid supplementation and that no differences in response could be shown between daily dosages of 250 and 500 mg of vitamin C.

153. **Strydom, N. B.; Rogers, G. G.; van der Walt, W. H.; and van der Linde, A.:**
Changes in the Level of Serum Vitamin C in Mine Workers.
J. So. Afr. Inst. Min. Metall., vol. 77, 1977, pp. 214-217.

Authors' Summary

The levels of serum vitamin C in the blood of mineworkers were determined on the first and fifth days of the normal heat-acclimatization period (i.e., before and after exposure to heat) and again after 1, 2, and 4 months of underground employment. Supplementary vitamin C was administered to the men during the heat-acclimatization period. Six groups of 20 men featured in the study and, except for one of the two 4-month groups, all the values were obtained after a full shift of underground work.

It was found that adequate levels of serum vitamin C were maintained during the heat-acclimatization period, and the 250 mg of vitamin C given daily to each man must therefore be regarded as sufficient. The serum vitamin C decreased significantly with time of exposure to underground conditions, showing that the vitamin C utilized during heat stress is more than that provided in the men's diet. At the end of 4 months, not a single subject had more than 0.4 mg of serum vitamin C per 100 ml, most of them having only 0.3 mg per 100 ml; 90% of the men had had more than 0.4 mg per 100 ml during the acclimatization period. It is therefore recommended that the mineworkers' diets should be supplemented with 100 to 200 mg of vitamin C per man per day.

154. **Strydom, N. B.; and Williams, C. G.:**
Effect of Physical Conditioning on State of Heat Acclimatization of Bantu Laborers.
J. Appl. Physiol., vol. 27, 1969, pp. 262-265.

Authors' Abstract

Two groups of 23 men each were first exposed to the standard heat test (32.2°C wb, 33.9°C db, and wind velocity of 0.4 m/sec) usually employed to assess the degree of acclimatization attained by laborers. Thereafter, one group was required to work in a temperature-controlled environment (21°C) at a high workload (1.5-1.6 l/min) for 4 hr each day for 12 days while the other group did

only light to moderate exercise (0.9–1.0 l/min) in the same environment. Both groups improved markedly with regard to their physical condition and gained approximately 2 kg in weight during the training period. On re-exposure to heat, however, there were significant improvements with respect to physiological responses to heat stress only during the first 2 hr. It is concluded that physical training in cool environments is not an adequate substitute for heat acclimatization.

155. Strydom, N. B.; Wyndham, C. F.; and Benade, A. J. S.:

The Response of Men Weighing Less Than 50 kg to the Standard Climatic Room Acclimatization Procedure.

J. So. Afr. Inst. Min. Metall., vol. 72, 1971, pp. 101–104.

Authors' Summary

A group of 23 underweight men weighing less than 50 kg were subjected to an acclimatization procedure in which the work rate was gradually increased from 35 W on the first day to 70 W on the eighth day. Excessively high body temperatures and heart rates were observed on these subjects throughout the acclimatization period and on their performance they must be rated as heat-intolerant. It can be concluded that such underweight men should not be subjected to acclimatization at such high work rates and that they should not be allocated to tasks involving these rates in a hot environment. The fact that their body surface areas are inadequate to enable them to get rid of the internal heat produced during strenuous work plus their low work capacities are the major reasons for their inability to tolerate heat.

156. van Ackern, G.:

Beziehung zwischen regionaler Verteilung der Schweißproduktion und Abweichung von der "Predicted 4-Hr Sweat Rate." P4SR. (Correlation Between Regional Distribution of Sweating and Deviation from the "Predicted 4-hr Sweat Rate." (P4SR))

Int. Z. Angew. Physiol., vol. 31, 1972, pp. 11–40.

Author's Abstract

For quantitative assessment of the regional distribution of sweating and its significance, the model of a cylinder sweating at a uniform rate is improved by considering, separately, the sweat production of arms, legs, and trunk (including head). Due to regional and individual variations, the amount of sweat evaporated (E) depends not only on the amount of sweat secreted (S) but also on the distribution of sweat on the body surface. The quotient S/C for E/C = 1.0 (C = evaporation capacity), which depends on the distribution of sweat, may be used for the following calculations: 1. Estimating the amount of sweat dripping off unevaporated, whenever the evaporation capacity is fully utilized; 2. predicting the individual ability to work in hot environments characterized by the same P4SR; and 3. judging the effect of an altered distribution of sweating upon the body surface (e.g., during acclimatization).

157. van Beaumont, W.; Young, H. L.; and Greenleaf, J. E.:

Plasma Fluid and Blood Constituent Shifts During Heat Exposure in Resting Men.

Aerospace Med., vol. 45, 1974, pp. 176–181.

Authors' Abstract

To investigate the mechanisms of plasma volume (PV), protein, and electrolyte shifts during exposure to heat, seven men (23 to 42 yr) were seated for 3 hr at $45.0^{\circ} \pm 1^{\circ}\text{C}$ T_{db} and 35% relative humidity. Venous blood samples were drawn without stasis before, during, and after heat exposure and were analyzed for hematocrit (Hct), hemoglobin (Hb), plasma Na, K, Cl, osmolarity, and total

protein. Proportional changes in PV were calculated from changes in Hct. During heat exposure (1) the mean percentage loss of PV was 2.9 times greater than the percentage loss of total body fluid; (2) any initial hemodilution appeared to be inversely related to the early rate of sweating; (3) the change in plasma protein concentration correlated -0.97 with the change in PV, but the plasma protein content was essentially constant, i.e., it varied <2.2%; and (4) the changes in plasma Na, Cl, and K content followed closely the variations in PV. The Hb/Hct was constant despite a nearly 3% increase in plasma osmolarity. It is concluded that, *in vivo*, changes in plasma osmolarity up to 10 mOsm/l do not appear to affect the red cell volume and, therefore, do not contribute any appreciable error in calculations derived from Hct values. The changes in PV during heat exposure in resting men are associated with variations in electrolyte content while the protein content remains essentially constant.

158. van Graan, C. H.; and Schutte, P. C.:
Microclimate Protection as a Method of Heat Acclimatization.
So. Afr. Med. J., vol. 52, 1977, p. 411.

Authors' Abstract

A cooling jacket with ice as coolant has been designed and tested in the mining industry. The jacket was developed to provide men working in hot underground environments with sufficient cooling to maintain acceptable body temperatures and thereby decrease or eliminate the risk of heat stroke.

Although this jacket proved to be efficient it has certain shortcomings; it has a relatively low cooling capacity, it is rather heavy, and it is difficult to distribute in underground conditions. Most of these problems have been eliminated by re-designing the jacket: instead of ice, dry ice is used as the coolant, and the construction of the jacket has been simplified. In terms of human physiological response, the new jacket's cooling capacity is identical to that of the original jacket.

As the dry ice jacket provides protection for 6-8 hr, and as it has been shown that men maintain their state of acclimatization while wearing the ice jacket, it was decided to investigate the acclimatization response of men wearing the dry ice jacket while doing active work in hot environments. It was found that the men became well acclimatized and that microclimate protection could be used as a method of heat acclimatization.

159. van Rensburg, A. J.; and Stewart, J. M.:
Selection of a Method to Measure Mean Skin Temperature.
So. Afr. Med. J., vol. 52, 1977, pp. 411-412.

Authors' Abstract

In heat exchange between man and his environment the outside surface of the skin of a nude man is the link between the environment and the human body. To calculate this heat exchange an accurate measure of this temperature is essential.

It may be shown theoretically that the method of determining the convective heat transfer coefficient from experiments covering a wide range of ambient temperatures may not be valid. The analysis showed how variations in uniformity of skin temperature could lead to different heat transfer coefficients.

In this regard it is (1) important to use a method that gives an accurate estimate of the mean skin temperature, and (2) necessary to establish the effect of different environmental conditions on the uniformity of skin temperature.

In previous work at our Division, nine different methods of measuring mean skin temperature have been compared with an optimal weighting system based on skin temperature measurements at 16 different sites on the body. The data indicate that one should be careful when selecting a method for measuring mean skin temperature, especially in environments below 25°C DB.

Data collected in various recent studies has been analysed to provide quantitative guidelines for the study and application of the heat transfer equations, as well as for the selection and application of a method to measure mean skin temperature.

Two subjects were exposed at four different metabolic rates (rest, 100, 200, and 300 W x m² surface area) to different environmental conditions ranging from 14°C (low humidity) to 41°C (high humidity) at a wind velocity of about 0.4 m x 5'. The different metabolic rates were achieved by stepping on and off adjustable stepping blocks at different stepping rates. After 50 min of exposure, the skin temperature was measured at 15 sites with a copper-constantan thermocouple. All necessary precautions for accurate temperature measurements were taken.

The mean of the temperatures for the two subjects were used in the analysis.

It is shown that below an air temperature of about 30°C the skin surface temperature becomes markedly non-uniform and may vary over the skin surface by more than 10°C. Above 30°C this non-uniformity decreases, and variations in the temperature of the skin surface decrease to less than 2°C.

It is also shown that when measuring mean skin temperature in an environment below 30°C one should use a method which measures the surface temperature at as many different sites as is practical.

It is concluded that accurate heat transfer calculations can be made at ambient temperatures above 30°C and that the problem requires further study at temperatures below this level.

160. Wagner, J. A.; Robinson, S.; Tzankoff, S. P.; and Marino, R. P.: Heat Tolerance and Acclimatization to Work in the Heat in Relation to Age. *J. Appl. Physiol.*, vol. 33, 1972, pp. 616-622.*

Authors' Abstract

Temperature regulation and acclimatization of groups of male subjects (ages 11-14, 15-16, 25-30, 20-29, and 46-67 yr) were compared in a standard work-heat stress; walking on the treadmill at 5.6 km/hr on the level for 40-90 min in dry heat (T_a 49.0°C, T_{wb} 26.6°C). Boys and the young men in the 25-30 age group were acclimatized in winter by eight consecutive daily treadmill walks in the hot room, the older men and the 20-29 age group by playing strenuous games in summer heat three times a week for 5-6 weeks. Before acclimatization, young men and the older boys tolerated the work in the heat longer and maintained lower heart rates (HR), and rectal (T_{re}) and skin (\bar{T}_s) temperatures, and greater evaporative rates in relation to T_{re} and \bar{T}_s than either the older men or the preadolescent boys. After acclimatization, thermoregulation during work in the heat was significantly improved in all age groups, but the young men and older boys were still superior to the preadolescent boys and older men. The improvements in evaporative cooling resulted in lower skin temperatures, with increased $T_{re} - \bar{T}_s$ gradients, and reduced coefficients of heat conductance. These changes indicate reductions in the requirement for cutaneous blood flow in heat transport, and thus reduced circulatory strain and heart rate during work in the heat. The older men had lower coefficients of heat conductance and finger blood flow in the heat than the young men. During work in the heat the older men and preadolescent boys were more limited in the sensitivity and secretory capacity of the sweating mechanism than the young men and the older boys.

*Same as: Wagner, J. A.; Robinson, S.; and Marino, R. P.: Heat Tolerance and Acclimatization in Relationship to Age. *Federation Proc.*, vol. 30, 1974, p. 209.

161. Wells, C.; and Buskirk, E.:
Body Temperatures During Contralateral Arm-Leg Exercise.
Med. Sci. Sports, vol. 4, 1972, pp. 37-42.

Authors' Abstract

Two lean and two obese women performed contralateral arm-leg exercise in environments maintained at two different "effective temperatures" of 21° and 29°C. Variations among relatively steady-state skin temperatures, subcutaneous temperatures, and three measures of core temperature were studied under two exercise loads, i.e., 25% and 50% $\dot{V}O_2$ max. Core and subcutaneous temperatures were found to increase directly with the work load performed. Skin temperatures were related to ambient temperatures, but decreased with higher work load performance. This decrease was attributed primarily to increased evaporative heat loss rather than to changes in blood flow distribution because the skin temperatures and the subcutaneous temperatures of active limbs exceeded those of contralateral inactive limbs. The subcutaneous-skin surface temperature gradient was greater at the lower environmental temperature, but increased directly with the work load in the warmer environment as a result of the increased subcutaneous and decreased skin temperatures.

162. Wells, C. L.; and Horvath, S. M.:
Heat Stress Responses Related to the Menstrual Cycle.
J. Appl. Physiol., vol. 35, 1973, pp. 1-5.

Authors' Abstract

Seven young adult female subjects were exposed to an environment of 48°C, 11 mm water vapor pressure, for 2 hr at each of three distinct menstrual phases. Cyclic changes in basal body temperature associated with ovulation were accompanied by significantly higher hemoglobin and hematocrit values during the ovulatory phase. Serum electrolyte (Na^+ , K^+ , and Cl^-) concentrations showed little relation to menstrual phase. There was a tendency toward higher heart rates and lower ventilation volumes during ovulatory phase heat exposures. No significant differences in core (rectal) or peripheral (skin) temperatures, oxygen consumption, or total body sweating rates occurred during phases of the menstrual cycle. Luteal phase sweating and evaporative rates tended to lag behind mean values obtained during the other two menstrual phases, but values were essentially equal by 40 min of heat exposure. Hemoglobin, hematocrit, plasma protein, and lactate values declined significantly with heat exposure while serum electrolyte concentration increased, suggesting blood dilution as a result of a shift in interstitial fluid. Lower Na^+ and Cl^- losses in total body sweat were observed during luteal phase heat exposures than during the other menstrual phases. The few differences occurring with menstrual cycle phase had minimal influence on ability of the female to regulate body temperature when exposed to environmental heat stress.

163. Wells, C. L.; and Horvath, S. M.:
Responses to Exercise in a Hot Environment as Related to the Menstrual Cycle.
J. Appl. Physiol., vol. 36, 1974, pp. 299-302.

Authors' Abstract

It has been shown previously that the menstrual cycle had minimal influence upon thermoregulation while young women rested in a hot-dry environment. In this study, an internal heat load (exercise) was added to the external heat load of a hot environment (48°C, 11 mmHg water vapor pressure). Seven untrained and heat unacclimatized young women rested for 40 min, walked for 40 min at a work load of 50% $\dot{V}O_2$ max, and rested again for an additional 40 min in the heat. No menstrual phase differences were found for such parameters as T_{re} , \bar{T}_s , \bar{T}_b , body heat content, sweating rate, evaporative heat loss, $\dot{V}O_2$, V_E , oxygen pulse, hemoglobin, hematocrit, or plasma proteins. Unexpectedly, the anticipated hemoconcentration consequent to exercise did not occur with

exercise in the heat. Apparently, water gain from the interstitial compartment was maintained at the same level as water loss from the skin, while electrolyte losses in sweat were higher proportionately than water losses.

164. Wells, C.; and Horvath, S. M.:

Metabolic and Thermoregulatory Responses of Women to Exercise in Two Thermal Environments.

Med Sci. Sports, vol. 6, 1974, pp. 8-13.

Authors' Abstract

Seven untrained and unacclimatized female subjects rested, walked for 40 min on a treadmill grade at 50% $\dot{V}O_2$ max, and recovered from exercise under two environmental conditions. The two conditions represented thermal neutrality ($T_A = 25^\circ\text{C}$) and a hot-dry ($T_A = 48^\circ\text{C}$) condition. Thermo-regulatory and metabolic measures were assessed. Significantly higher levels of $\dot{V}O_2$, $\dot{V}E$, and heart rate occurred during exercise and recovery in 48°C compared to 25°C . Ventilation equivalent and oxygen pulse values suggested reduced metabolic efficiency in the heat. Resting T_{re} initially decreased in the heat returning to control values within 40 min. Comparable changes were not evident during rest in 25°C . The change in T_{re} occurring with exercise in the heat was double that in the 25°C condition. Body heat content rose 9 kcal/m^2 during the exercise period in the 25°C environment but was elevated 45 kcal/m^2 during the walk in the heat. The heat load of the 48°C environment altered thermal balance such that changes in circulatory and respiratory response mechanisms resulted in increased metabolic requirements.

165. Wheeler, E. F.; el-Neil, H.; Wilson, J. O. C.; and Weiner, J. S.:

The Effect of Work Level and Dietary Intake on Water Balance and the Excretion of Sodium, Potassium and Iron in a Hot Climate.

Br. J. Nutr., vol. 30, 1973, pp. 127-137.

Authors' Summary

1. The dietary intake, and urinary, cutaneous and fecal loss of water, sodium, potassium and iron have been studied in young men living and performing moderate work in a hot climate. The dietary intakes of K and Fe were lowered during part of the study.

2. The subjects were already somewhat acclimatized to heat; further acclimatization was achieved when they were performing work, and this was assessed in terms of the increase in their rate of sweating.

3. The subjects tended to be in marginally negative Na balance, partly owing to lowered Na intakes. Intakes and outputs of K were in balance. Losses of K in sweat amounted to 15% of intake when the dietary level was reduced.

4. The subjects were slow in adapting to changes in Fe intake, 8 days being an insufficient period for adaptation after their intake had been halved. Losses of Fe in sweat were approximately 0.3 mg/day or one-third of the estimated requirement for absorbed Fe.

5. It is concluded that Fe losses in sweat could be a significant factor in Fe depletion if dietary Fe was low or unavailable, as there was no evidence that a low intake and absorption affected sweat losses.

166. Wilkins, D. C.:

Heat Acclimation in the Antarctic.

J. Physiol. (London), vol. 214, 1971, pp. 15P-16P.

Author's Abstract

During the hard physical work associated with sledging in the Antarctic, in spite of the low environmental temperatures, it is usual for men to sweat. It seemed possible that a degree of heat acclimatization might be demonstrated as a result of arduous dog-sledge journeys.

Eight men who were members of the British Antarctic Survey base at Halley Bay ($75^{\circ}31'S.$) were studied before, during and after sledging journeys which totalled some 4,000-5,000 man-miles. Body temperatures were monitored intermittently during the journeys, using the temperature sensitive radio pill. For 50% or more of the time spent sledging, body temperatures were above 37.5°C and occasional values as high as 38.5°C were recorded. This in spite of environmental temperatures averaging -14°C whilst traveling and sometimes falling to -35°C . The average wind velocity over the same period was 5 m/sec.

Before and after each journey, measurements of sweat rate were made using a modification of the controlled hyperthermia technique. The subject was clad in an impermeable P.V.C. suit and lay in a bath of warm water, the temperature of which was controlled. Sweat was collected in intermittent evacuation of the suit for an hour, during which time the body temperature was maintained at 38°C .

Sweat rates were significantly increased after some spring and autumn sledging journeys of only 2 weeks duration. Longer summer journeys lasting 10 weeks produced as much as a twofold increase in the sweat rate.

It is concluded that a degree of acclimatization to heat was achieved as a result of the increased body temperature and sweating during polar journeys.

167. Williams, C. G.; and Heyns, A. J. A.:

Differential Acclimatisation as a Function of Duration of Exposure.

Int. Z. Angew. Physiol., vol. 27, 1969, pp. 198-211.

Authors' Summary

The length of time required to achieve the highest degree of acclimatization was studied in two groups of men who were acclimatized at either one of two temperature conditions, namely $32.2^{\circ}/33.9^{\circ}\text{C W.B./D.B.}$ or $33.9^{\circ}/35.5^{\circ}\text{C W.B./D.B.}$ The acclimatization procedure consisted of 4 hr work daily at a metabolic rate of 5 kcal/min for the duration of 12 days. Changes in rectal temperature and heart rate followed immediately upon the first exposure to, and work in, heat. Judged by the rectal temperature reactions, the process of acclimatization was completed within 8 days. An extension of the period of acclimatization to between 9 and 12 days was without effect on the state of acclimatization acquired by the subjects after an 8-day procedure. With an acclimatization procedure shorter than 8 days the men were not fully acclimatized. Acclimatization procedures of either 4, 5, or 6 days duration (at $32.2^{\circ}\text{C W.B.}$) induced a degree of acclimatization in the subjects which proved to be adequate to enable them to work with body temperatures similar to those of fully acclimatized men, for periods of either 1, 2, or 3 hr, respectively in the test environment.

168. Williams, C. G.; and Wyndham, C. H.:
Heat Reactions of U. S. Students During a Multitemperature Test.
J. Appl. Physiol., vol. 24, 1968, pp. 800-808.

Authors' Abstract

Ten US students were studied at effective temperatures (ET) of 25.4°, 28.7°, 31.0°, and 32.2°C. Rectal temperatures, heart rates, and sweat rates were recorded hourly while the men worked continuously for a period of 3 hr at a metabolic rate of 5 kcal/min. Functional relationships between sweat rate and rectal temperature were examined on both an hourly and a two-hourly basis. Curves fitted to the hourly data had a characteristic nonlinear relationship. The curve for the second hour fell below that for the first hour, and that for the third hour fell below that for the second hour. Other points which emerged were: (1) the preliminary "warm-up" of 30 min work at 5 kcal/min in comfortable air conditions raised heart rates at rest in the climatic chamber by 5 beats/min and rectal temperature at rest by 0.35°C; (2) oral and tympanic temperatures were similar and lower than rectal temperatures; and (3) an ET of 32.2°C should definitely be included in this heat-stress test because marked differences in responses showed up at this condition which were not apparent in lesser heat-stress conditions.

169. Williams, C. G.; Wyndham, C. H.; and Heyns, A.:
The Problem of "Optimum" Acclimatization.
Int. Z. Angew Physiol., vol. 26, 1968, pp. 298-308.

Authors' Summary

A study was carried out on three groups of 20 male subjects to determine the combination of environmental stress and a standard rate of work of 5 kcal/min that will give the "optimum" level of acclimatization.

Each group was acclimatized at one of three temperature conditions (wet-bulb temperatures of 32.2°, 33.9°, and 35.6°C) and thereafter tested also under the remaining two conditions.

The degree of acclimatization was judged by the physiological reactions to a standard work rate of 5 kcal/min at the various wet-bulb temperatures. The test at a wet-bulb temperature of 32.2°C revealed that "optimum" acclimatization was obtained when men were acclimatized at 33.9°C W.B. The test at 33.9°C W.B. illustrated that the physiological reactions of the group acclimatized at 35.6°C W.B. were decidedly poor when compared to those of the groups acclimatized at 32.2° and 33.9°C W.B. The test carried out at 35.6°C W.B. showed that, irrespective of the wet-bulb temperature at which the men were acclimatized, their heat tolerance to the test environment was poor.

170. Winsman, F. R.; Soule, R. G.; and Goldman, R. F.:
Underclothing and its Physiological Effects in a Hot-Dry Environment.
Cloth. Res. J., vol. 5, 1977, pp. 28-34.

Authors' Abstract

When underclothing of any type is worn, data collected using our static, copper manikin clearly indicate a slightly increased insulation and decreased evaporative transfer. In order to assess air movement in the dynamic state (pumping), the present study involved eight men (21.2 yr, 175.2 cm and 69.1 kg) to evaluate four underclothing systems worn under a desert uniform; (a) no under-wear; (b) standard boxer shorts and t-shirt; (c) fish net 'Brynje'; and (d) ladder net 'Brynje'. The physiological trial was designed using the copper man data to select an environment and work combination which would maximize the physiologic differences expected. Accordingly, each subject walked at 4.8 km/hr with each system (40 min walk, 20 min rest and 40 min walk) at 49°C, 20%

r.h. ($\sim 29^{\circ}\text{C}$ T_{WB}). Three point mean weighted skin temperature (MWST), rectal temperature (T_{re}), heart rate (H.R.) and sweat production (P) and evaporation (E) were measured. The results obtained showed that: (1) no underwear resulted in significantly lower MWST after 60, 80, and 100 min; (2) T_{re} was slightly lower at a given time interval with no underwear; (3) there was a rise in heart rate during the work periods, but no differences among underwear systems; (4) sweat production showed no differences; (5) the ratio of evaporated-produced sweat (E/P) showed that no underwear allowed better evaporative cooling ($P < .01$) than any of the other three systems. Neither fish nor ladder net underwear appear to offer any advantage over regular underwear; subjective comfort ratings support these conclusions from the physiologic data.

171. Wyndham, C. H.; Benade, A. J. A.; Williams, C. G.; Strydom, N. B.; Goldin, A.; and Heyns, A. J. A.:

Changes in Central Circulation and Body Fluid Spaces During Acclimatization to Heat.

J. Appl. Physiol., vol. 25, 1968, pp. 586-593.

Authors' Abstract

Arterial-venous differences (using the acetylene rebreathing technique), oxygen consumption, and heart rates were measured on six subjects, and cardiac output and stroke volume were calculated on days 1, 3, 5, 7, 9, 13, and 17 of acclimatization to heat (4 hr of work daily at 1.0 liter/min oxygen consumption at 33.9°C DB, 32.2°C WB and air movement of 0.5 m/sec). Plasma volume, extracellular volume, and total body water were determined with albumin- ^{131}I , ^{82}Br , and H₃O, respectively, before acclimatization, and again on days 5 and 17. Cardiac outputs and A-V differences did not change significantly; oxygen consumption rose on the first few days in heat and then returned to control values; heart rate rose to a mean of 153 beats/min on day 1 and fell to 126 beats/min by day 3; stroke volume fell sharply on day 1 but rose to close to control values by day 3. The increase in stroke volume was associated with an increase by day 5 in volumes of plasma, extracellular space, and total body water. The first two spaces decreased between days 5 and 17. It is postulated that both ADH and aldosterone are involved in the increase in the three body fluid spaces in the first 5 days of acclimatization as a result of the "emergency" of central circulatory instability which stimulates the volume receptors in the vascular system.

172. Wyndham, C. H.; Kew, M. C.; Kok, R.; Bersohn, I.; and Strydom, N. B.:

Serum Enzyme Changes in Unacclimatized and Acclimatized Men Under Severe Heat Stress.

J. Appl. Physiol., vol. 37, 1974, pp. 695-698.

Authors' Abstract

The serum enzymes, glutamic oxaloacetic and pyruvic transaminases (GOT and GPT), lactic dehydrogenase (LDH), and creatinine phosphokinase (CPK), of 30 unacclimatized and 15 acclimatized volunteer miners were measured at rest and again after either 4 hr of exercise at 1.3 l/min oxygen consumption at 32.2°C wet-bulb temperature, 33.8°C dry-bulb temperature and air movement of 0.4 m/sec, or after withdrawal from the experiment because of a rectal temperature of greater than 40°C , heat syncope, or exhaustion. A control study was done at room temperature on the acclimatized men. No increase in serum enzyme levels was found after exercise at room temperature, but both GOT and CPK increased significantly in the unacclimatized and acclimatized men after exercise in heat. GOT, GPT, LDH, and CPK levels in the acclimatized men were significantly higher after exercise in heat than at room temperature. Thus, exercise in heat that raised body temperatures above 39°C resulted in a significant increase in serum enzymes. However, the increases observed were neither as consistent nor of the same order as those observed in heat stroke cases. A clear distinction thus exists between the enzyme changes that follow exercise in heat and those seen in heat stroke.

173. Wyndham, C. H.; Rogers, G. G.; Senay, L. C.; and Mitchell, D.:
Acclimatization in a Hot, Humid Environment: Cardiovascular Adjustments.
J. Appl. Physiol., vol. 40, 1976, pp. 779-785.

Authors' Abstract

Four trained young men worked for 4 hr/day at 40-50% of their maximum aerobic capacity, first for 3 days at 25°C db, 18°C wb, and then for 10 consecutive days at 45°C db, 32°C wb. This portion of the study was mainly concerned with central circulatory changes during acclimatization. The central circulatory adaptation to work in heat could be divided into four distinct phases: phase I (*day 1*) was characterized by a progressive fall in stroke volume (SV) during heat exposure but cardiac output (CO) was maintained above control values by high heart rates. Phase II (*days 2 and 3*) was marked by increases in SV and decreases in heart rate but with little change in CO from phase I. During phase III (*days 4-8 of acclimatization*), CO increased due to increases in SV. Phase IV (*days 6-8*) was associated with decreases in rectal and skin temperature toward control levels. SV and HR both decline in this phase so that CO was not elevated greatly above control levels. The results indicated that central circulatory and temperature regulating events are not causally associated in acclimatization.

174. Wyndham, C. H.; Strydom, N. B.; Benade, A. J. S.; and van der Walt, W. H.:
The Effect on Acclimatization of Various Water and Salt Replacement Regimens.
So Afr. Med. J., vol. 47, 1973, pp. 1773-1779.

Authors' Abstract

A study was conducted to determine whether the speed and degree of acclimatization achieved with the climatic room procedure were affected by different amounts of water intake, salt replacement, or both. Four groups of men underwent the normal climatic room acclimatization procedure; each group was provided with different amounts of water, salt, or both, during the daily 4-hr acclimatization period. The quantities given were 1 liter, 2 liters and 3 liters of water, and 2 liters of water containing 6 g of sodium chloride.

The 3-liter group gave the best performance during the acclimatization period in that these men showed a significantly lower incidence of oral temperature of 38.3°C (101°F) or above, than those of other groups. No significant differences could be observed between groups in the degree of acclimatization achieved. It is therefore concluded that there is no advantage to be gained from adding salt to drinking water during acclimatization procedures, and that it is essential to provide at least 3 liters of water/man/4-hr period of acclimatization.

175. Wyndham, C. H.; Strydom, N. B.; Benade, A. J. S.; and van Rensburg, A. J.:
Limiting Rates of Work for Acclimatization at High Wet Bulb Temperatures.
J. Appl. Physiol., vol. 35, 1973, pp. 454-458.

Authors' Abstract

Samples of 12-14 unacclimatized men were acclimatized for 9 successive days (4 hr of continuous work each day) at six different combinations of V_{O_2} (covering the work rate range of light, moderate, and hard work) and wet bulb temperature (the air was saturated with water vapor and air movement was 0.4 m/s). The study showed that because some men developed rectal temperatures in excess of 40°C each day, it was impossible to acclimatize these men in the following combinations: (1) 0.65 l/min and 35.6°C; (2) 0.95 l/min and 33.9°C; and (3) 1.45 l/min and 32.2°C. Men were successfully acclimatized in the following combinations: (1) 0.65 l/min and 33.9°C; (2) 0.95 l/min and 32.2°C; and (3) 1.45 l/min and 30.6°C. These results indicate that men can be acclimatized

at P₄SR index values of 5.0, but not 7.5. They also showed that the men were better acclimatized for moderate and hard work in hot, humid heat by a regime of hard work and moderate environmental heat than by light work and more severe environmental heat.

176. Wyndham, C. H.; Strydom, N. B.; Benade, A. J. S.; van Rensburg, A. J.; and Rogers, G. G.: Heat Stroke Risks in Unacclimatized and Acclimatized Men of Different Maximum Oxygen Intakes Working Under Hot and Humid Conditions. Chamber of Mines of South Africa, Project No. 19/A720.64, 1972, p. 1-17.

Authors' Summary

The maximum oxygen intakes of 41 Bantu recruits to a mine were measured before and after the men had undergone climatic room acclimatization. Important results and conclusions are the following:

1. Over the period of acclimatization there was a significant increase in mean maximum oxygen intake (from 2.39 to 2.82 liters/min) and of mean body weight (from 61.6 to 62.1 kg).
2. The body temperatures, after 3 hr of work under heat stress, were correlated significantly with maximum oxygen intake of the men in both the unacclimatized ($r = 0.50$) and acclimatized ($r = 0.41$) states, but not with body weights or ages, in the ranges of body weights and ages of the men in this sample. Further analysis using regression equations indicated that 25% of the differences between individuals in body temperature could be accounted for by differences between them in maximum oxygen intake. Of the factors investigated in this study, maximum oxygen intake was therefore the main determinant of differences in body temperature.
3. The body temperatures of 17 out of 100 *unacclimatized* men with maximum oxygen intakes of less than 2.0 liters/min are liable to reach heat stroke levels during the first few days of acclimatization, whereas only 3 of 100 recruits with maximum oxygen intakes of more than 2.0 liters/min run this risk. The figures indicate that the risks of recruits reaching high body temperatures in acclimatization would be significantly reduced if those with low maximum oxygen intakes were to be identified by the stepping test and excluded from normal acclimatization. The position in this respect is not straightforward, however, because, although up to 30% of new recruits currently show high temperatures in the first few days of acclimatization, the majority of these men acclimatize successfully when exposed to a second cycle of acclimatization, and only about 5% have then to be classified as heat intolerant. Moreover, as indicated above, the maximum oxygen intakes of many recruits increase during acclimatization. It would therefore reduce the availability of acclimatized manpower significantly if all low-working-capacity men were to be identified in advance and excluded from acclimatization.
4. The chances that the body temperatures of *acclimatized* men with maximum oxygen intakes of more than 2.5 liters/min will reach heat stroke levels are 100 times less than they are in the case of *acclimatized* men with maximum oxygen intakes less than 2.5 liters/min.
5. It is deduced from the above that there is a strong case for the application of the step-test procedure immediately *after* acclimatization, and for the classification of men into those with maximum oxygen intakes of 2.5 liters/min and above as being capable of shovelling and tramping rock in hot areas and for the classification of men with maximum oxygen intakes of less than 2.5 liters/min as being fit for only light work in hot conditions. It is suggested that if these two groups of men could be classified in this way and kept in separate work categories underground, by means of different colored armbands, the gold mining industry would go a long way towards the final elimination of heat stroke.
6. Finally the results of this study underline the risks associated with the acclimatization of men with low maximum oxygen intakes at the work rates necessary to provide them with adequate protection underground. They also emphasize the heavy responsibilities which are carried by acclimatization supervisors in regard to the detection of high temperature cases during acclimatization.

177. Wyndham, C. H.; Strydom, N. B.; van Rensburg, A. J.; Benade, A. J. S.; and Heyns, A. J.: Relation Between \dot{V}_{O_2} max and Body Temperature in Hot, Humid Air Conditions. *J. Appl. Physiol.*, vol. 29, 1970, pp. 45-50.

Authors' Abstract

Six men were conditioned to a step-climbing routine, followed by \dot{V}_{O_2} max determinations on a treadmill. They then worked for 4 hr at the step-climbing routine at T_{wb} 32.3° (saturated) and low air movement. Relating fourth-hr rectal temperatures to % \dot{V}_{O_2} max showed that the higher the percentage of maximum used, the higher was the fourth-hr rectal temperature. The men were then acclimatized for 12 days to identical conditions. Measurements of \dot{V}_{O_2} max showed no significant change from preacclimatization values. A similar close relationship was observed between the fourth-hr rectal temperature and % \dot{V}_{O_2} max. In the acclimatized state the six men were also studied at 50% \dot{V}_{O_2} max. Fourth-hour rectal temperature showed a close relationship with % \dot{V}_{O_2} max, the residual variance being only 0.288. The plots of fourth-hr rectal temperature against O_2 consumption, however, showed wide but consistent differences between individuals in rectal temperature responses, which are probably due, in part, to differences between them in \dot{V}_{O_2} max (or to some other body size parameter which is closely associated with \dot{V}_{O_2} max).

178. Yousef, M. K.; and Dill, D. B.: Sweat Rate and Concentration of Chloride in Hand and Body Sweat in Desert Walks: Male and Female. *J. Appl. Physiol.*, vol. 36, 1974, pp. 82-85.

Authors' Abstract

The rate of sweating from hand and from body and the concentration of chloride in sweat were studied in desert walks at 100 m/min in seven males and four females. Hand temperature (T_h) either was high in hands exposed to the sun or low in hands immersed in ice water. Volume of hand sweat (V_{sh}) was measured using rubber gloves. Mean values for V_{sh} and for Cl concentrations (Cl_{sh}) were about the same at the same T_h for right and left hands. In a saturated environment, V_{sh} and Cl_{sh} were higher in sweat collected from hot hands than in sweat from cold hands. This relationship was independent of sex and age. The Cl_{sh} was higher than Cl_s in sweat from the body (Cl_{sb}), and the ratio Cl_{sb}/Cl_{sh} was higher when hands were cold than when they were hot. Variations in Cl_{sb} were not related to T_{re} , sex, nor age. Females walked in the forenoon; their body sweat rate was lower than in males who walked in the afternoon when heat load was greater. In males SR in $g/min \cdot m^2$) = $6.67 + 3.38 (\Delta T_{re})$; in females the relation was SR = $6.94 + 1.05 (\Delta T_{re})$.

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